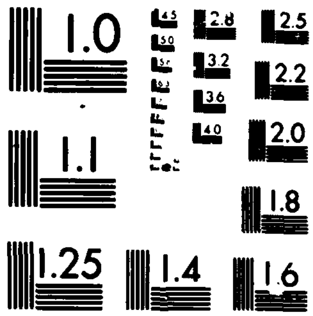
AD-A082 084 RAND CORP SANTA MONICA CA F/G 17/7
PERFORMANCE CONSIDERATIONS FOR IMAGE MATCHING SYSTEMS.(U)
DEC 79 J A RATKOVIC F49620-77-C-0023
UNCLASSIFIED RAND/N-1217-AF NL

END
DATE
FILMED
4-80
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 14 RAND N-1217-AF

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle) 6 Performance Considerations for Image Matching Systems.

5. TYPE OF REPORT & PERIOD COVERED 9 Interim rept.,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s) 10 J. A. Ratkovic

8. CONTRACT OR GRANT NUMBER(s) 15 F49620-77-C-0023

9. PERFORMING ORGANIZATION NAME AND ADDRESS
The Rand Corporation
1700 Main Street
Santa Monica, California 90401

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Requirements, Programs & Studies Group (AF/RDQM)
Ofc, DCS/R&D & Acquisition
Hq USAF, Wash. D. C. 20330

12. REPORT DATE 11 Dec[redacted]79

13. NUMBER OF PAGES ~~35~~ 12 79

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report) UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

No Restrictions

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Air-to-Surface Missiles
Navigation
Mapping
Position Indicators
Missiles

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See Reverse Side

296600

DD FORM 1 JAN 73 1473

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

This Note describes the underlying factors which affect system performance--accuracy of match and probability of false match--in map matching systems. Methods for improving system accuracy are discussed. A methodology for managing false fix probability during the acquisition phase is developed. Rules for accommodating various types of system problems in terms of preprocessing, scene selection, and algorithm choice are put forward. Finally, simulation results are presented to verify the discussion. (Author)

12

N-1217-AF

December 1979

PERFORMANCE CONSIDERATIONS FOR IMAGE MATCHING SYSTEMS

J. A. Ratkovic

A Rand Note

prepared for the

United States Air Force

Rand
SANTA MONICA, CA. 90406

PREFACE

The accurate guidance of its strategic and conventional cruise missiles is a matter of great concern to the Air Force. There are at present two methods of improving the location accuracy of the vehicle beyond that provided by the onboard inertial system. The first involves time-of-arrival techniques in the Global Positioning System (GPS). Earlier Rand studies of the performance cost and vulnerabilities of this system have shown that a "survivable" GPS system would cost several billion dollars and still may be vulnerable to jamming in the terminal area; thus, terminal delivery in the presence of jamming may not be accurate enough to allow for the delivery of nonnuclear munitions.

The second method, a potentially cheaper alternative to GPS guidance, is correlation guidance. A correlation guidance system using terrain contours (TERCOM) is configured as the heart of the guidance system for the present-generation cruise missile. Eventually, there will be a need for a navigation system that can go anywhere in the world, including to the flat areas where terrain-contour navigation fails, and possibly for the delivery of nonnuclear munitions on both strategic and tactical targets. Correlation guidance schemes using imagery (instead of terrain contours) along the midcourse flight path and in the terminal area are a potential means of achieving these goals.

Current Rand studies are providing a better understanding of the basic principles and limitations of the image-correlation system. They should also provide a methodology for improving the scene selection process and yielding a higher accuracy per fix. Aimed at the problems encountered in using imagery--especially those of radiometrics, in which the Air Force is heavily engaged--this Note is intended to be a first step in providing a unified theory for describing all matching processes (both pattern recognition and correlation) and for understanding the effects of inherent scene characteristics on the performance of the system.

This work was performed under the Project AIR FORCE research project "Battle Management System for ICBMs, Bombers, and Cruise Missiles."

This Note should be of general interest to researchers in the fields of map matching and pattern recognition, as well as to policy planners concerned with map matching for weapon guidance.

This Note is the second in a series dealing with map matching. It uses the basic structure of the first Note, N-1216-AF, as a starting point for discussing performance considerations associated with map matching systems. This Note and the previous Note approach the map matching problem from a physical point of view.

ACKNOWLEDGMENTS

My appreciation goes to Ted Garber for reviewing this Note and providing many worthwhile suggestions. A special thanks goes to Ed Conrow (Aerospace Corporation) and Lloyd Mundie for their contribution in defining the amount of contrast reversal that is likely to occur at various sensor wavelengths.

I wish to gratefully acknowledge the computer contributions of Marianne Lakatos and her mathematical assistance.

CONTENTS

I. INTRODUCTION

A-042-094

As discussed in N-1216-AF, the correlation process can be structured as shown in Fig. 1. This structure reduces the error sources to four generic categories, describes the preprocessing as either intensity or spatially related, places all matching algorithms into four categories (ranging from pure feature matching to ordinary correlation), and describes scenes statistically as homogeneous or heterogeneous, with each homogeneous region described by the number of independent elements it contains.

The major advantage of structuring the matching process in this manner is that the problem segments itself nicely, as shown in Fig. 2, in associating error accommodation with a single element or several separate elements of the system. Global errors are accommodated in preprocessing. Geometric distortions are handled by spatially grouping the elements so that the system performance is not severely degraded by the maximum amount of distortion anticipated. Global errors of an intensity nature are accommodated by normalizing the data in preprocessing before any matching is attempted. Nonstructural errors can be accommodated to some extent in mission planning. Routing to avoid potential obscuration and masking problems can reduce system vulnerability to these errors. Timing of the mission can also have an impact on shadows, area blockages, and possibly weather-related effects over the target area. There will always be some nonstructured errors which cannot be predicted or accommodated, and one must hope that their effect on system performance will not be significant. Regional errors can either be accommodated by improved signature modeling or by designing the matching algorithm to be invariant to regional errors. One extreme is to tailor the signature to the arrival of the vehicle over the target area, and the other is to do little modeling of the signature but compensate for it by using a feature matching algorithm. Compensation of local errors is generally achieved only in the matching algorithm.

It is the purpose of this Note to examine the effect of these various errors and of the scene composition on the performance of map

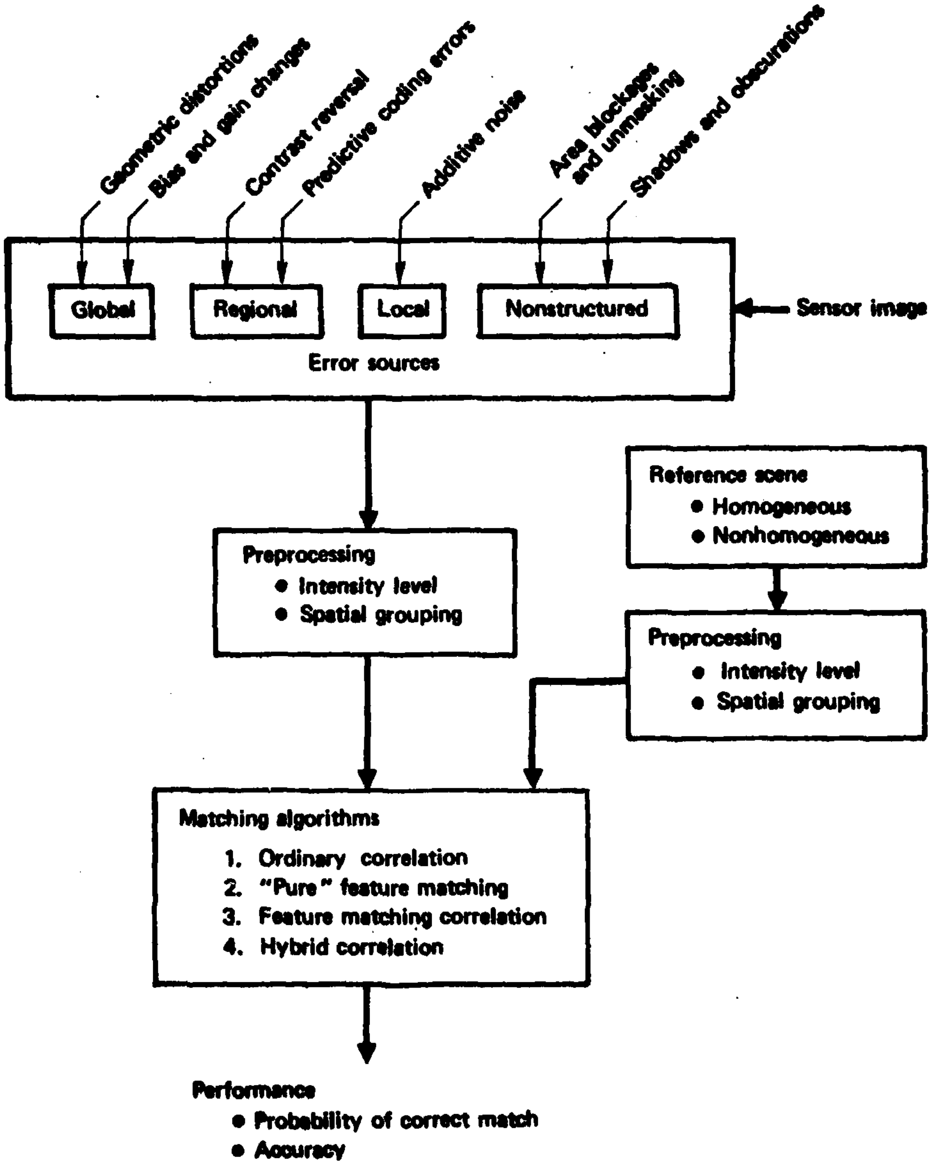


Fig. 1 — Generic overview of map matching process

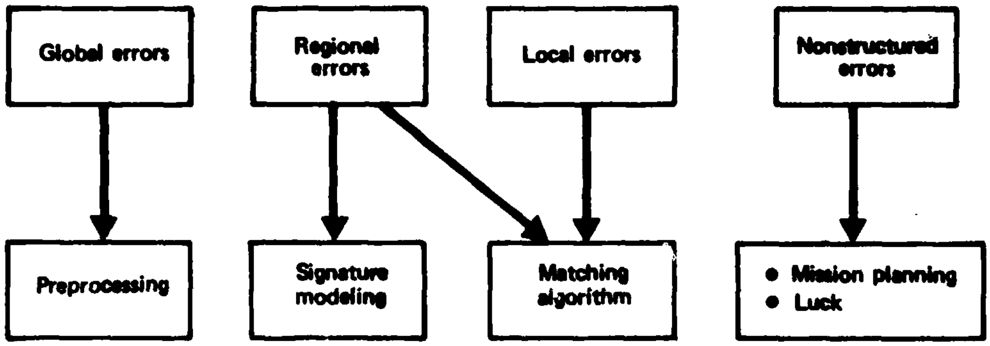


Fig. 2 — Error accommodation

matching systems. The two performance indices of interest are the probability of correct match, P_c, and the accuracy associated with the fix position. They can be considered independently of each other, as indicated in Fig. 3. The correlation process can usually be implemented in two phases; the first is an acquisition phase (designed to locate the general vicinity of the match position) and the second is to achieve maximum accuracy. In the discussion that follows, these topics will be treated separately.

In this Note we assume that the reference map is larger than the sensed image, and that the sensed image is wholly contained within the boundaries of the reference map. The reference and sensor maps can be broken down statistically into a set of features or homogeneous regions which comprise the entire map. Each region can be considered to be made up of a number of independent elements. An independent element may be composed of one or more sensor elements or pixels depending upon the degree of correlation between elements. Thus, the hierarchy of scene structure becomes scene, region, independent element, and element.

Section II of this Note describes the various factors which influence system accuracy and cause false matches. Section III describes techniques for improving system accuracy.

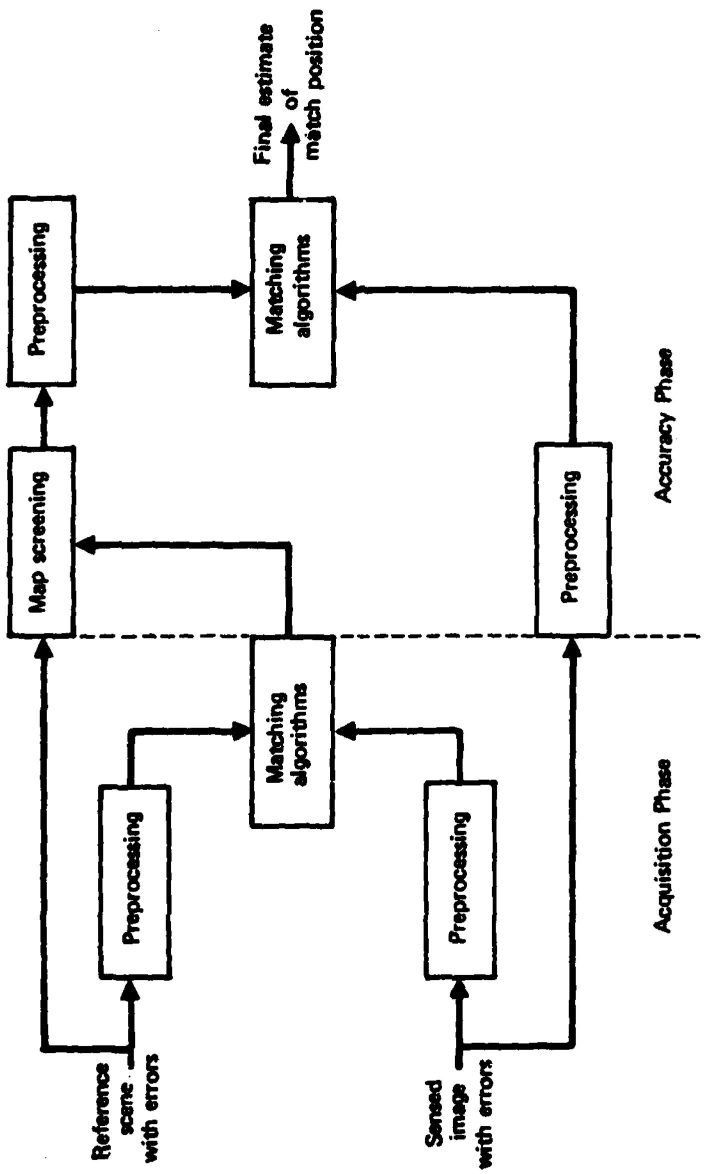


Fig. 3 — Acquisition and accuracy phases of map matching process

Section IV discusses acquisition problems and is broken into two segments. The first segment deals with the scene selection problem relative to acquisition, and the second segment examines the possible design tradeoffs between error types and matching algorithms.

II. UNDERLYING FACTORS AFFECTING SYSTEM PERFORMANCE

The output of the matching process will either be a correct match (where one is concerned with the accuracy* of the fix) or a false fix (where one is concerned with measuring the probability of occurrence (P_f) or nonoccurrence (P_c)).

ACCURACY

Intuitively, one can qualitatively relate the system accuracy to the shape of the correlation surface surrounding the time match location. A sharp peak at this point would be indicative of a high accuracy fix; a flattened surface surrounding the correct match position would suggest degraded accuracy. Three questions arise about system accuracy. What drives it? How does one quantify it? How does one develop methods for improving it? One might also ask how the parameters of accuracy and probability of correct match, P_c, relate to one another. They are obviously related in some sense, but the question is only academic. If one considers a two-phase implementation process in which the first phase is designed for maximizing acquisition and the second phase (possibly with different algorithms and preprocessing from the first phase) is designed to maximize the accuracy of the position fix, then one is not concerned with their relationship because they can be considered independently.

The discussion of accuracy will focus on examining the major driving factors in the process and a means of quantifying these factors. This section will also suggest methods for improving accuracy; however,

*Accuracy is not taken here to be the ultimate system accuracy which involves interpolation of the correlation peak, but rather accuracy is taken to refer to the width of the region around the true correlation peak in which a correlation point is likely to occur. The width of this region can be measured in map displacement positions which are generally one pixel apart. In general, accuracies have been reported by participants in the DARPA Terminal Homing Program to be on the order of one-pixel bias error with an additional one-pixel standard deviation about that bias. Thus, the absolute accuracy will depend upon the ground resolution of the sensor.

that topic will be considered in more detail in the following section. It will be shown that the degree of scene nonhomogeneity and geometric errors are the major parameters that influence accuracy. The discussion which follows starts with the homogeneous random map case and after nonhomogeneities are introduced into the scene drastic changes are observed in the correlation surface. An examination of real-world scenes shows that accuracy can be improved by decomposing the scene into homogeneous segments. This procedure is examined in more detail in Section III.

Let us start by examining how scene composition affects the correlation surface. First we will consider a completely random scene with elements generated from a Gaussian distribution with zero mean and unit variance. The random scene consists of 20 × 20 elements (pixels) which we shall call the reference map. From the center of this map we shall extract a 10 × 10 element sensor scene which we shall designate the control map. This sensor scene is then correlated with respect to the reference map to obtain the horizontal (x,y) autocorrelation contours (correlation height versus displacement position) about the center of the map (see Fig. 4(a)). Also displayed in Fig. 4(a) is an estimate* of the number of independent elements in the scene. For this control map with no interpixel correlation (because all scene elements are independently randomly generated) the estimation process determined there to be 97 independent elements (N_I) in a scene of 100 elements (N). We can use this parameter N_I as a quantitative measure both of the number of independent elements in the scene and of the spreading and contraction of the correlation peak about the match point.

To simulate the effect of nonhomogeneity introduced into a random scene, the control scene was altered by adding a constant value, μ, to all the map elements in the left-hand portion of the scene, as illustrated in Fig. 5. The mean level between the two regions was varied such that the bias level difference between the two regions would be comparable to, or larger than, the variation in the mean intensity of each region. Four bias levels were chosen: (1) $\mu = 0$ (control case shown in Fig. 4(a)), (2) $\mu = 1$ (Fig. 4(b)), (3) $\mu = 10$ (Fig. 4(c)),

*Taken from R-2211-AF, *Estimation Techniques and Other Work on Image Correlation*, J. A. Ratkovic et al., September 1977.

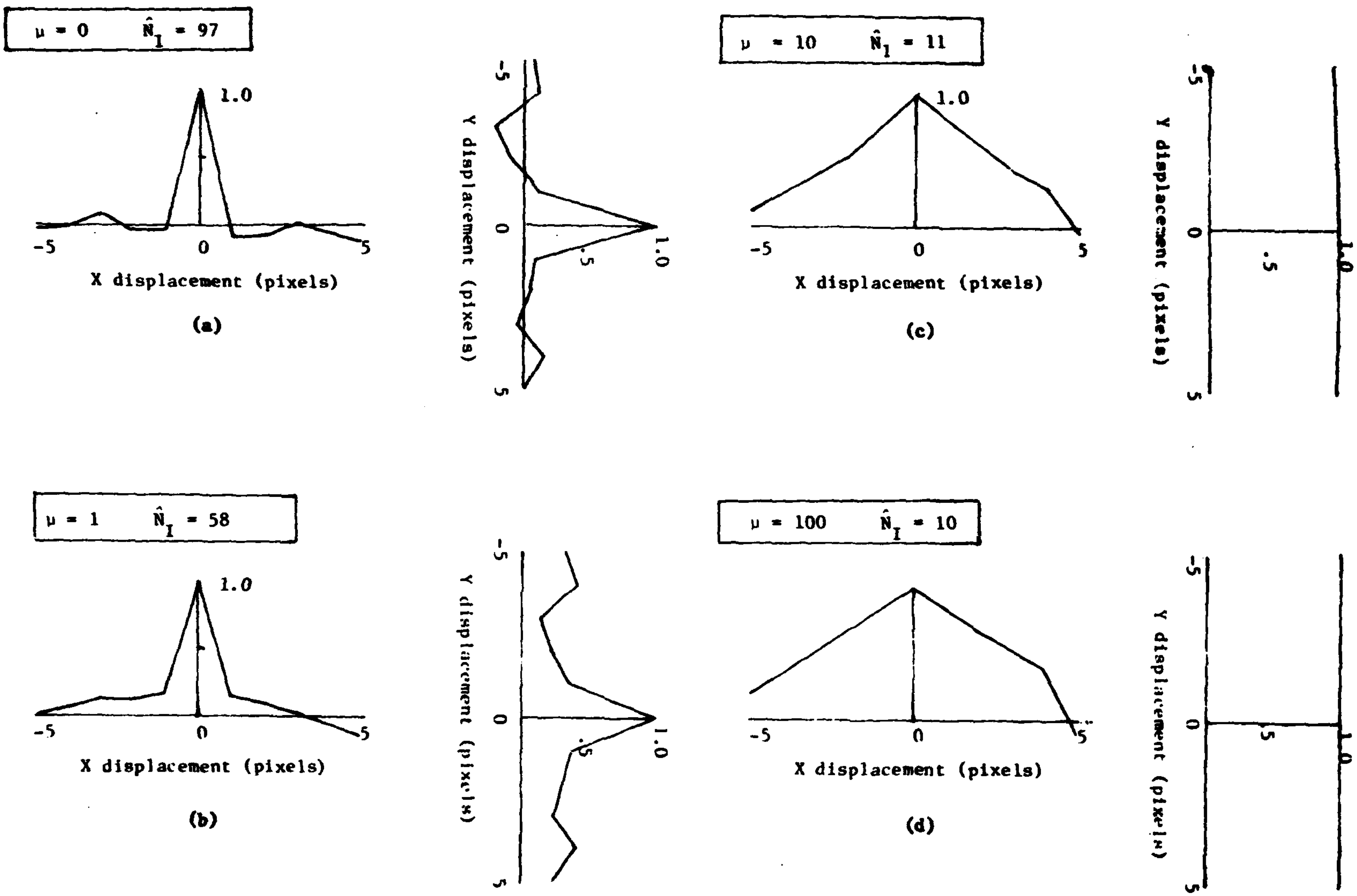


Fig. 4 — Effects of bias shifts

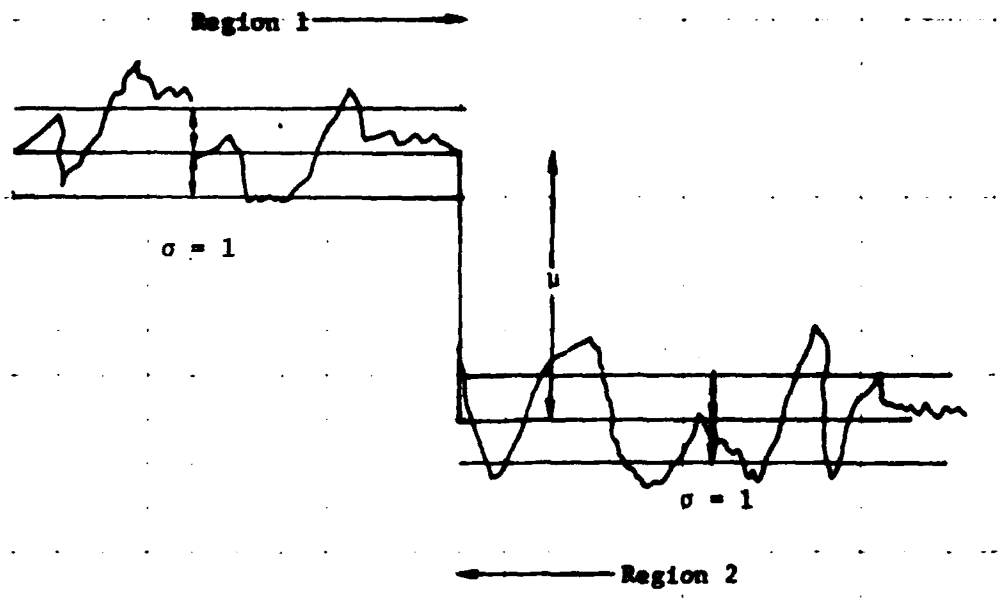


Fig. 5 — Geometry for change in bias levels between regions

and (4) $\mu = 100$ (Fig. 4(d)). As seen in Fig. 4, as a bias level between regions is added (with the magnitude of the bias level comparable to the variation in signal level in each homogeneous region), the correlation contours become more drawn out and the estimate of the number of independent elements, N_I, decreases to a value between the maximum number governed by the total number of independent scene elements (100) and the minimum number governed by the number of homogeneous regions contained within the scene (2). As the bias level between regions becomes significantly greater than the intensity variation in each region ($\mu = 10$ and $\mu = 100$ cases), the correlation contours become flatter and flatter, and the estimated number of independent scene elements becomes smaller (N_I reduces to two as $\mu \gg \sigma$ intensity).

The conclusion to be drawn from this simple example is that for nonhomogeneous scenes (practically all real-world scenes), when the variation in intensity within a region is small relative to the mean intensity level differences between regions, the correlation process is dominated by the number and size of homogeneous regions composing the scene. It would then appear that in most real-world situations where the map covers a number of homogeneous regions the intensity level variation within a homogeneous region has very little effect on the correlation surface. To demonstrate this hypothesis, we selected several areas (agricultural, mountain, suburban, and desert) from an Earth Resources Satellite (ERTS) map to conduct an experiment. In this experiment we divided the maps (both sensor and reference) into homogeneous regions and replaced the intensity value of each pixel in a region with the average intensity level of the region. The results of this experiment are shown in Fig. 6. It is seen that the correlation contours with and without intensity variations in the region are very similar, indicating that the mean intensity value of the homogeneous region is the dominant factor in the correlation process and not the individual interpixel variations within the regions, assuming the intensity variation within the region to be small relative to the difference in mean intensity level between homogeneous regions.

Thus, from the aforementioned experiments it appears that the number of homogeneous regions, their size, and the mean intensity value associated with the region are the major scene contributors to the correlation process. From a descriptive point of view we can consider a random (zero correlation between pixels) homogeneous scene in one dimension (as illustrated in Fig. 7) correlating to a first approximation as a Dirac delta function. On the other hand, nonhomogeneous scenes can be viewed as a first approximation in one dimension, as a series of square waves with small amplitude variations about the mean amplitude level due to interpixel intensity differences within the region. The autocorrelation surface for this process then looks like the convolution of two square waves with the width of the peak around the match point being determined by the size of the homogeneous region.

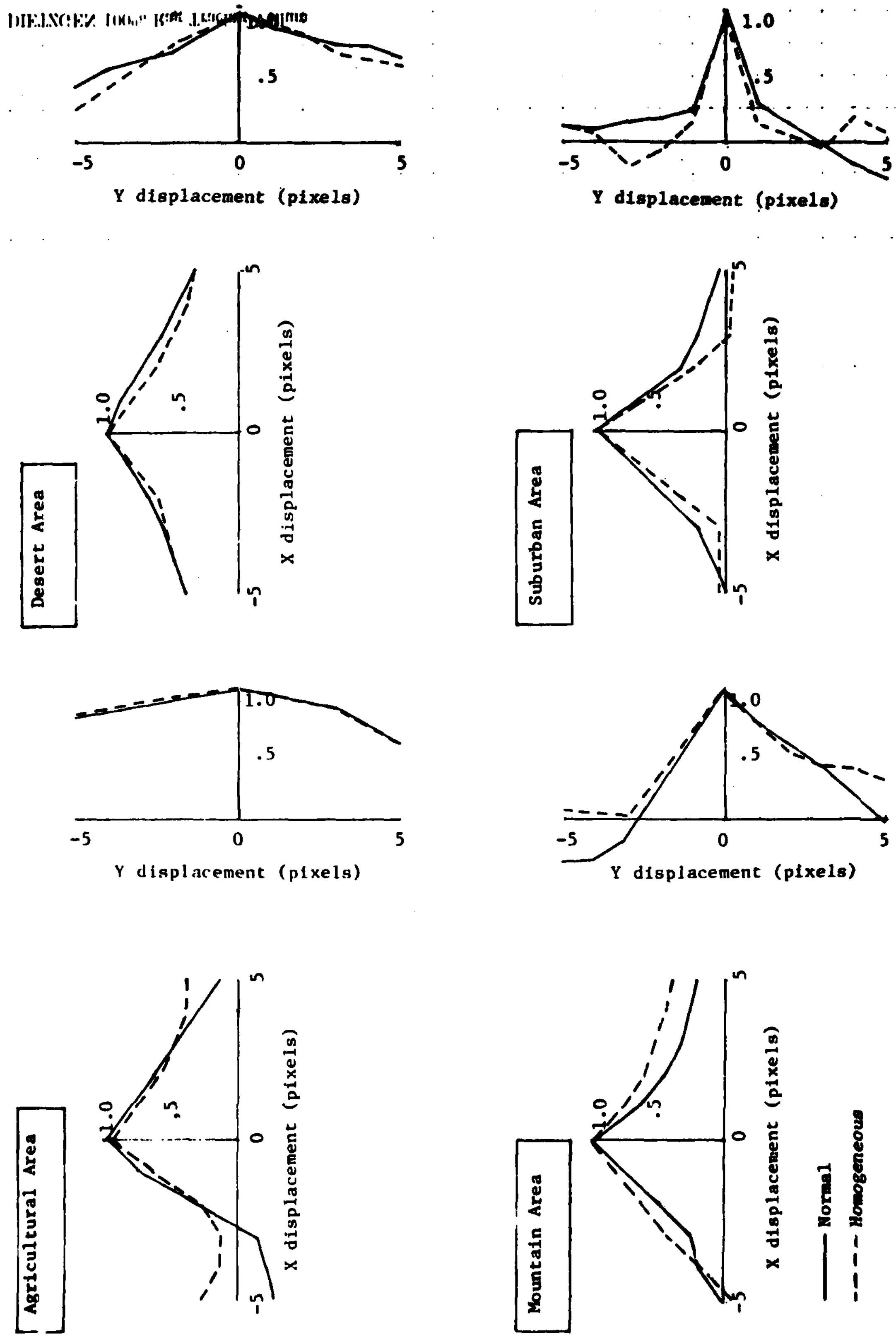


Fig. 6 — Autocorrelation contours with and without intensity variation in homogeneous regions

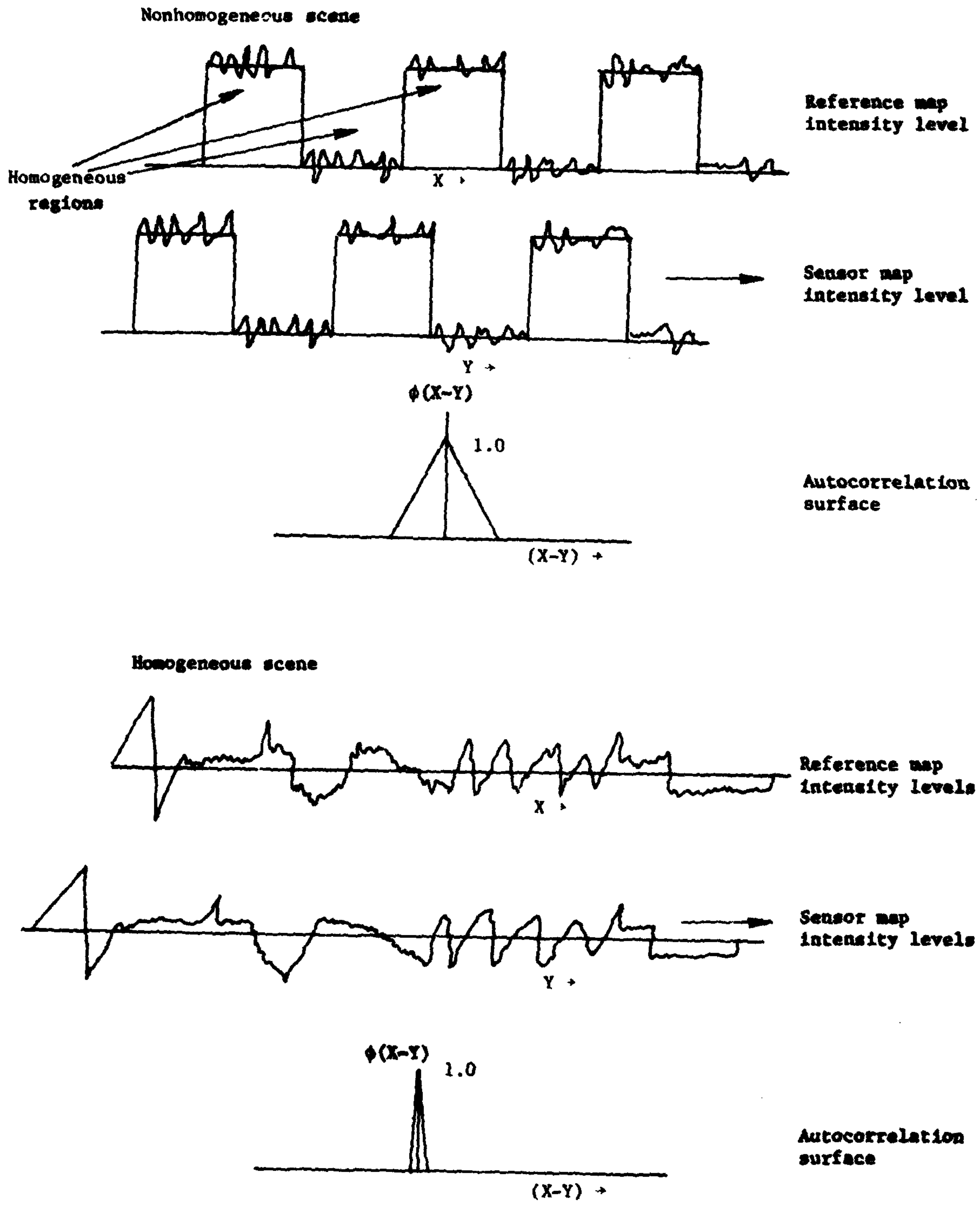


Fig. 7 — Autocorrelation surface φ(X-Y) for homogeneous and nonhomogeneous scenes

In general, there is also structure within a homogeneous region which can be categorized by "independent elements" within the region. It is this finer structure which allows correlation systems to work in homogeneous regions; otherwise, if there were only one independent element within the region (i.e., constant intensity level), one could not distinguish a correlation peak. As a second approximation, then, one could view the intensity variations contained within the homogeneous regions shown in Fig. 8 as independent elements. Each region can be considered composed of a number of independent elements whose size ultimately limits the resolution of the scene. Each independent element in turn is composed of a number (at least one) of spatially connected pixels which can be considered to be independent of neighboring groups of independent pixels. Thus, an overview of the process might consider the signal to be modulated by the size and magnitude of the homogeneous regions (low frequency modulation) and the size and magnitude of the independent elements contained within the region (high frequency modulation).

Up to this point we have shown that the correlation peak is generally dominated by the nonhomogeneous characteristics* of the scene. There is also, however, some contribution to the peak width from interpixel correlation, i.e., if we were to remove the nonhomogeneity from the scene we would still obtain some spreading of the correlation surface due to independent elements contained within the region. This is where the literature concerning the subject becomes somewhat vague. Generally the literature uses the term "correlation length" to describe the width of the correlation surface and uses this term for both the interpixel correlation between elements and the total scene correlation. There are in fact two correlation terms--the interpixel correlation which we shall define by a correlation length, α, and the total scene correlation which we shall define as the scene resolution parameter, N/N_I, where N is the total number of resolution elements (pixels) in the scene. These terms cannot be equated unless the scene is homogeneous.

*Mean intensity levels of regions within the scene.

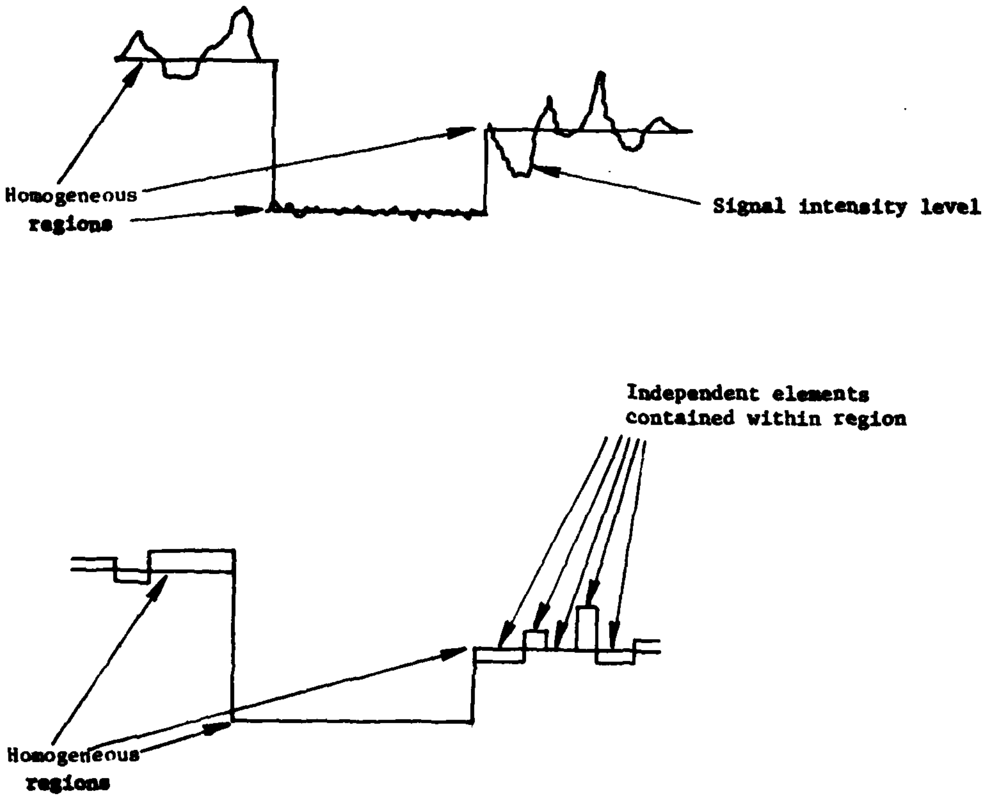


Fig. 8 — Scene decomposition into regions and independent elements

To illustrate these points we will decompose the scene into homogeneous regions and autocorrelate a sensor and reference scene using the standard product algorithm, a feature matching algorithm, and a hybrid correlation matching algorithm, all of which were described in N-1216-AF. The feature matching algorithm essentially removes the effect of homogeneous regions since all homogeneous regions are zero-meaned and normalized separately. The hybrid algorithm, on the other hand, takes out some but not all of the effects of the scene nonhomogeneity. Figure 9 shows the effect of using these three different algorithms upon the correlation surface for four different scenes. The normal autocorrelation process produces a spread out correlation peak, while the feature matching algorithm (homogenizing both the reference and sensor scene) produces the sharpest correlation peak, being limited only by the interpixel correlation. The hybrid algorithm produces a correlation surface between the two indicating that it does remove some but not all of the effects of scene nonhomogeneity.

Many authors in the field have shown that accuracy can be improved through the use of edge operators (gradients, Laplacians, etc.) or the use of spatial frequency filtering. These results are consistent with the explanation given here for the effect of homogeneous regions on system accuracy. Spatial frequency filters which cut off the lower spatial frequencies associated with homogeneous regions will improve system accuracy (provided, of course, that acquisition has been accomplished). Similarly, edge operators will significantly reduce the broadening effects of homogeneous regions and their effectiveness should be equivalent to correlation matching techniques which account for features in the scene (feature matching correlation and hybrid correlation algorithms).

To summarize, the dominant scene parameters contributing to the correlation process are the size and number of homogeneous regions composing the scene. The interpixel correlations and intensity variations between pixels, represented by the number and size of independent elements within the region, are only significant for completely homogeneous scenes (which are rare) and for scenes which have been homogeneously processed. Conversely, by homogeneously segmenting the scene,

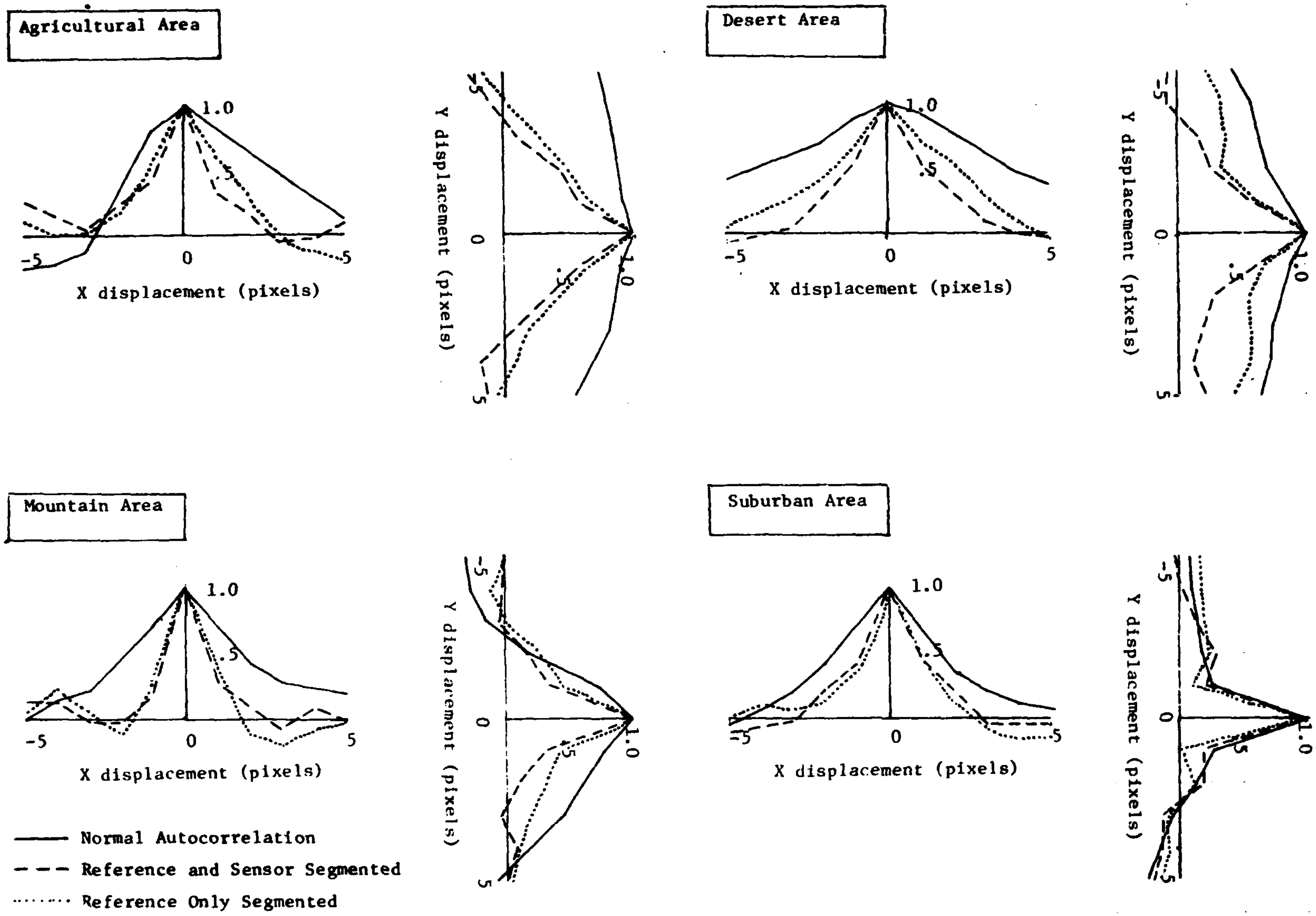


Fig. 9 — Effects of homogeneous segmentation

sharper correlation peaks can be produced whose widths are limited only by the interpixel correlation or the size of the independent elements.

The effects of geometric distortions on the correlation surface have been described in the literature and are similar to the effects of introducing nonhomogeneity into the scene. Basically, geometric distortions spread out the correlation peak and reduce its maximum value. For illustrative purposes, Table 1 shows how the degree of congruence between the sensor and the reference image is decreased as the scale factor (ρ) is increased.

The effect of regional, local, and nonstructured error sources is to reduce the peak of the correlation surface at the match point, but not necessarily to spread out the correlation surface.

OCCURRENCE OF FALSE MATCHES

There are two basic mechanisms (in the extreme) which can cause false peaks to dominate the correct match peak. These basic mechanisms can be attributed to either random noise or repetitive spatial patterns in the scene. For the latter mechanism, we consider the situation where the spatial pattern of homogeneous regions within the scene is replicated or nearly replicated in other parts of the reference scene. Extreme examples where these individual mechanisms can cause a false match by themselves can be illustrated by a random map case and by a checkerboard pattern.

In the case of a "randomly generated" map, there is not (or at least should not be) any spatial structure to the map so that the addition of a sufficient quantity of noise can result in a false match. The location of the false match position should occur randomly throughout the correlation surface with different noise samples. In the other case, the existence of a repetitive pattern for the reference scene (e.g., multiple smokestacks) can lead to a false match even in the absence of any significant system errors such as noise.

In real-world systems, false matches are caused by a combination of the two mechanisms--spatial pattern repetition and other system errors, including noise. Generally speaking, mathematical models have been developed only for the homogeneous scene case with the basic

Table 1

RELATIVE MAGNITUDE OF OVERLAP AREA WITH MAGNIFICATION ERRORS

Map size: 10 x 10

Scale Factor	Magnitude of Overlap Area									
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$\rho = 1$	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.02	1.47	0.02	0.0	0.0	0.0	0.0
$\rho = 1.01$	0.0	0.0	0.0	0.0	1.47	96.04	1.47	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.02	1.47	0.02	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	2.25	12.00	2.25	0.0	0.0	0.0	0.0
$\rho = 1.1$	0.0	0.0	0.0	0.0	12.00	64.00	12.00	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	2.25	12.00	2.25	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.25	1.25	1.50	1.50	1.50	1.25	0.25	0.0	0.0
	0.0	0.0	1.25	6.25	7.50	7.50	7.50	6.25	1.25	0.0	0.0
	0.0	0.0	1.50	7.50	9.00	9.00	9.00	7.50	1.50	0.0	0.0
$\rho = 1.5$	0.0	0.0	1.50	7.50	9.00	9.00	9.00	7.50	1.50	0.0	0.0
	0.0	0.0	1.50	7.50	9.00	9.00	9.00	7.50	1.50	0.0	0.0
	0.0	0.0	1.25	6.25	7.50	7.50	7.50	6.25	1.25	0.0	0.0
	0.0	0.0	0.25	1.25	1.50	1.50	1.50	1.25	0.25	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00
	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00	2.00
	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00
	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00
	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00
$\rho = 2$	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00
	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00
	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00
	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00
	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00
	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00

failure mechanism being the additive noise case. The nonhomogeneous scene case, even for the simple additive noise failure mode, is much more difficult to model, and being very scene dependent does not give a great deal of insight into the interaction between cause (error) and effect (change in system performance). The mathematical modeling problem becomes even more difficult when one attempts to model the scene structure, potentially introducing nearly repetitive spatial patterns into the process. The complicated failure mechanism, the difficulty in modeling the scene including its structure, and the impossibility of defining a "typical scene" forces one rather rapidly into a simulation mode for answers to the effects of errors on system performance. However, that is not to say that some of the mathematical models are not useful in giving one an initial design point to work from. A number of theoretical analyses have provided us with a starting point for the simple noise/homogeneous scene case, but the more complicated repetitive spatial pattern/nonhomogeneous case has not been treated, to date, mathematically.

III. METHODS FOR IMPROVING SYSTEM ACCURACY

Section II laid the groundwork for understanding the accuracy and false match issues. In this section, we continue that discussion and concentrate on methods for sharpening the correlation peak. We focus on the utility of various algorithms for improving accuracy, and because accuracy can be considered a separate issue from the acquisition problem, we are not concerned with the problem of false matches that is sometimes aggravated by such algorithms. That subject is treated in a subsequent section of this Note. Finally, this Note does not deal with the ultimate system accuracy achievable, which involves interpolation of the correlation peak; however, one might expect, based on other simulation work,* that accuracies (CEP) on the order of one to two pixels can be expected.

As pointed out in the previous section, segmentation of the scene into homogeneous regions can improve system accuracy. This can be done automatically by employing either a pure feature matching algorithm or by utilizing a feature matching correlation algorithm. The other problem is to improve accuracy in the presence of geometric distortion. One can obviously improve the local accuracy by shrinking the size of the map that one is working with; however, it is not clear (unless the target itself is a small distinctive area contained within the sensed image) that the overall accuracy can be improved significantly by locally matching parts of the scene due to the mapping error resulting from relating multiple points of match to the target area.

To illustrate further the effects on accuracy of homogeneously segmenting the map, we took a 20 × 20 element map from mountain, desert, and suburban areas. Each of these three maps had more than one homogeneous region. Thirty-six 5 × 5 element sensor maps were correlated over each of the three scenes, and a number of scene parameters, including N_I and the scene resolution, N/N_I (the indicator of system accuracy), were computed for each submap in the region. The results are

*DARPA's Terminal Homing Program.

tabulated in Tables 2 through 4. Also shown in the tables are the mean and standard deviation of the scene resolution for each area. The results, using the ordinary or standard correlation procedure (normalized product algorithm), are compared later for the same maps using a feature matching correlation algorithm in which both the sensor and the reference scenes are segmented homogeneously.

In the mountain area for the unprocessed case, the scene resolution varied from about one pixel (which is an accuracy equal to the sensor resolution) to almost seven pixels with an average value of three pixels and a relatively large standard deviation of 1.7 pixels. In the desert area, the scene resolution varied from about two pixels to about five, with a mean of 3.3 pixels and a standard deviation of 0.8 pixel. In the suburbs, the scene resolution varied from one to three pixels, with a mean of two pixels and a standard deviation of 0.8 pixel. Thus, even within a small area in a scene there can be significant variations in the scene resolution because of the variation in homogeneous regions overlapped by the sensor maps in a given area. This variation in scene resolution will decrease as the sensor map size grows (because the number of homogeneous regions contained in a large map generally will not change drastically in a given region). However, even though the standard deviation in scene resolution will decrease with increasing map size, the magnitude of the scene resolution will remain high* in nonhomogeneous scenes compared with a completely homogeneous map. This high scene resolution value will decrease accuracy in the correlation process. By segmenting the map, the effects caused by the interface of homogeneous boundaries are eliminated and the scene resolution and accuracy become dependent only on the interpixel correlation in the segmented regions, and not on the bias level difference between regions.

Correlations were performed using the feature matching correlation algorithm for each of the submaps in each of the three areas. The N_I and scene resolution parameters for this case are also shown in Tables 2 through 4. In the mountain area, the scene resolution was confined to values between 1 and 1.5 pixels, with an average value of 1.3 pixels and a standard deviation of 0.2. In the desert area, the scene

*Low scene resolution $N/N_I \approx 1$ (high resolution) high accuracy; high scene resolution $N/N_I \approx N$ (low resolution) low accuracy.

Table 2

NO-NOISE PARAMETERS FOR UNPROCESSED/HOMOGENEOUSLY SEGMENTED SCENES
Mountain Area
5 × 5 Sensor Map
20 × 20 Reference Scene
N/N_I = Scene Resolution

Row \ Column	1	2	3	4	5	6	Noise-Free Parameter
1	1.92/ 1.36	1.48/ 1.30	1.06/ 1.29	1.06/ 1.22	0.75/ 1.16	1.10/ 1.41	$N/\hat{N}_I$
	13.00/18.30	16.90/19.20	23.60/19.40	23.60/20.50	33.20/21.50	22.80/17.70	$\hat{N}_I$
2	1.85/ 1.11	1.53/ 1.10	1.45/ 1.02	0.97/ 1.01	1.82/ 1.14	2.71/ 1.15	$N/\hat{N}_I$
	13.50/22.50	16.40/22.50	17.20/24.40	25.80/24.90	13.70/21.80	9.20/21.70	$\hat{N}_I$
3	2.26/ 1.23	2.32/ 1.40	2.04/ 1.46	1.55/ 1.63	4.17/ 1.30	4.65/ 1.08	$N/\hat{N}_I$
	11.10/20.30	10.80/17.90	12.30/17.00	16.20/15.40	6.00/19.30	5.40/23.20	$\hat{N}_I$
4	2.49/ 1.38	2.88/ 1.46	2.51/ 1.45	3.03/ 1.65	5.33/ 1.37	5.42/ 1.15	$N/\hat{N}_I$
	10.00/18.10	8.70/17.10	9.90/17.20	8.30/15.40	4.70/18.30	4.60/21.80	$\hat{N}_I$
5	3.03/ 1.28	3.32/ 1.28	2.82/ 1.43	4.75/ 1.50	6.23/ 1.30	5.85/ 1.41	$N/\hat{N}_I$
	8.30/19.50	7.50/19.60	7.90/17.50	5.70/16.70	4.00/19.20	4.30/18.40	$\hat{N}_I$
6	2.28/ 1.35	2.73/ 1.57	3.10/ 1.85	6.12/ 1.49	6.60/ 1.56	5.13/ 1.39	$N/\hat{N}_I$
	11.00/18.50	9.20/15.90	8.00/13.50	4.10/16.80	3.80/17.20	4.40/18.00	$\hat{N}_I$

Statistics of Scene Resolution ($N/\hat{N}_I$) over Mountain Area

	Mean, $N/\hat{N}_I$	$\sigma_{N/\hat{N}_I}$
Unprocessed scene	3.01	1.68
With homogeneous segmentation	1.84	0.18

Table 3

NO-NOISE PARAMETERS FOR UNPROCESSED/HOMOGENEOUSLY SEGMENTED SCENES
Desert Area
5 × 5 Sensor Map
20 × 20 Reference Scene
N/N_I = Scene Resolution

Row / Column	1	2	3	4	5	6	Noise-Free Parameter
1	2.12/ 1.59	2.49/ 1.53	3.20/ 1.56	4.05/ 1.74	4.29/ 1.62	4.52/ 1.52	$N/\hat{N}_I$
	11.70/15.70	10.00/16.30	7.80/16.00	6.20/14.40	5.80/15.40	5.50/16.50	$\hat{N}_I$
2	2.90/ 2.18	3.27/ 1.47	3.59/ 1.36	4.04/ 1.54	4.36/ 1.81	4.66/ 1.65	$N/\hat{N}_I$
	8.60/11.50	7.60/17.00	6.90/18.40	6.20/16.20	5.70/13.80	5.40/15.20	$\hat{N}_I$
3	2.62/ 2.48	2.84/ 1.59	3.11/ 1.24	3.43/ 1.27	4.22/ 2.04	4.48/ 2.04	$N/\hat{N}_I$
	9.60/10.10	8.80/15.70	8.00/20.20	7.30/19.60	5.90/12.30	5.60/12.30	$\hat{N}_I$
4	1.98/ 1.89	2.39/ 1.79	2.85/ 1.61	3.40/ 1.94	3.91/ 2.74	3.92/ 2.73	$N/\hat{N}_I$
	12.60/13.70	10.40/13.90	8.80/15.50	7.30/12.90	6.40/ 9.10	6.40/ 9.10	$\hat{N}_I$
5	1.72/ 1.64	2.50/ 1.71	3.22/ 1.82	3.60/ 2.27	3.22/ 2.55	2.45/ 2.07	$N/\hat{N}_I$
	14.50/15.30	10.00/14.60	7.80/13.80	6.90/11.00	7.80/ 9.80	10.20/12.10	$\hat{N}_I$
6	3.11/ 1.66	3.56/ 1.96	3.94/ 2.10	3.93/ 2.10	3.09/ 2.39	2.01/ 1.77	$N/\hat{N}_I$
	8.00/15.10	7.10/12.80	6.30/11.90	6.40/10.50	8.10/10.40	12.50/14.10	$\hat{N}_I$

Statistics of Scene Resolution (N/N_I) over Desert Area

	Mean, $N/\hat{N}_I$	$\sigma_{N/\hat{N}_I}$
Unprocessed scene	3.30	0.78
With homogeneous segmentation	1.87	0.39

Table 4

NO-NOISE PARAMETERS FOR UNPROCESSED/HOMOGENEOUSLY SEGMENTED SCENES
Suburban Area
5 × 5 Sensor Map
20 × 20 Reference Scene
N/N_I = Scene Resolution

Row / Column	1	2	3	4	5	6	Noise-Free Parameters
1	1.41/ 1.24	1.44/ 1.19	1.72/ 1.46	2.49/ 1.89	3.26/ 1.80	2.29/ 1.68	$N/\hat{N}_I$
	17.90/20.10	17.40/20.90	14.50/17.10	10.10/13.20	7.70/13.90	11.00/19.80	$\hat{N}_I$
2	1.26/ 1.10	1.36/ 1.07	1.62/ 1.15	2.34/ 1.44	3.26/ 1.52	2.51/ 1.53	$N/\hat{N}_I$
	19.80/22.80	18.30/23.50	15.40/21.70	10.70/17.40	7.70/16.50	9.90/16.30	$\hat{N}_I$
3	1.12/ 1.07	1.11/ 1.18	1.19/ 1.03	2.22/ 0.99	3.21/ 1.31	2.38/ 1.37	$N/\hat{N}_I$
	22.20/23.30	22.50/21.00	20.90/24.20	11.30/25.20	7.80/19.00	10.50/18.20	$\hat{N}_I$
4	1.55/ 0.96	1.56/ 1.04	1.27/ 1.07	1.99/ 1.24	2.92/ 1.36	2.16/ 1.25	$N/\hat{N}_I$
	16.10/26.00	16.00/23.90	19.80/23.30	12.60/20.10	8.60/18.40	11.60/19.80	$\hat{N}_I$
5	1.98/ 0.98	2.13/ 1.09	1.52/ 0.99	1.67/ 1.21	2.75/ 1.41	2.16/ 1.34	$N/\hat{N}_I$
	12.60/25.60	11.80/22.90	16.40/25.20	15.00/20.60	9.10/17.80	11.60/18.60	$\hat{N}_I$
6	1.85/ 1.11	2.29/ 1.29	1.70/ 1.24	1.63/ 1.22	2.29/ 1.39	1.90/ 1.22	$N/\hat{N}_I$
	13.50/22.60	10.90/19.40	14.70/20.10	15.30/20.40	10.90/17.90	11.10/20.40	$\hat{N}_I$

Statistics of Scene Resolution ($N/\hat{N}_I$) for Suburban Area

	Mean, $N/\hat{N}_I$	$\sigma_{N/\hat{N}_I}$
Unprocessed scene	2.02	0.605
With homogeneous segmentation	1.26	0.22

resolution varied between 1.5 to 2.5 pixels, with a mean of 1.9 pixels and a standard deviation of 0.4 pixel. In the suburban area, the scene resolution varied between 1 and 2 pixels, with a mean of 1.2 pixels and a standard deviation of 0.2 pixel. In all cases, the scene resolution was reduced significantly (a factor of 2 in the desert, 3 in the suburbs, and 8 in the mountains) and the variation in scene resolution among regions (mountain, desert, and suburbs) was less pronounced. Thus, system accuracy can be improved by using map matching algorithms which emphasize features or homogeneous regions in the scene.

The area around the true match point in which the extremum correlation values fall is indicative of the accuracy or "acquisition basket." To test the utility of the "scene resolution" as an estimator for both the acquisition basket size and the tightness of the acquisition basket when a feature matching correlation algorithm is used, a Monte Carlo simulation was run for a number of different scenes. This Monte Carlo simulation was performed for both the ordinary correlation algorithm (normalized product) and the feature matching correlation algorithm (both the reference and sensor scenes homogeneously segmented). This simulation consisted of taking the original scene and adding white Gaussian noise to each sensor element, correlating the images, and locating the displacement position of best match. This process was repeated 25 times and the locations of the correlation matches relative to the correct match location are recorded in Fig. 10. Shown in this figure are representative results for four different scene resolutions using the ordinary correlation algorithm. The circled position indicates the location of the true match and the number in each displacement position represents the number of simulation runs for which that displacement position was chosen to be the match point. As illustrated in this figure, the larger the "scene resolution" value, the greater the probability that a number of the match points will occur in an area adjacent to the correct match point (an area bounded by the sensor resolution). Thus, the scene resolution does indicate the size of an acquisition basket around the true match point where the correct match points are likely to fall. The smaller the scene resolution, the more likely the correct match point will occur within the area of one pixel

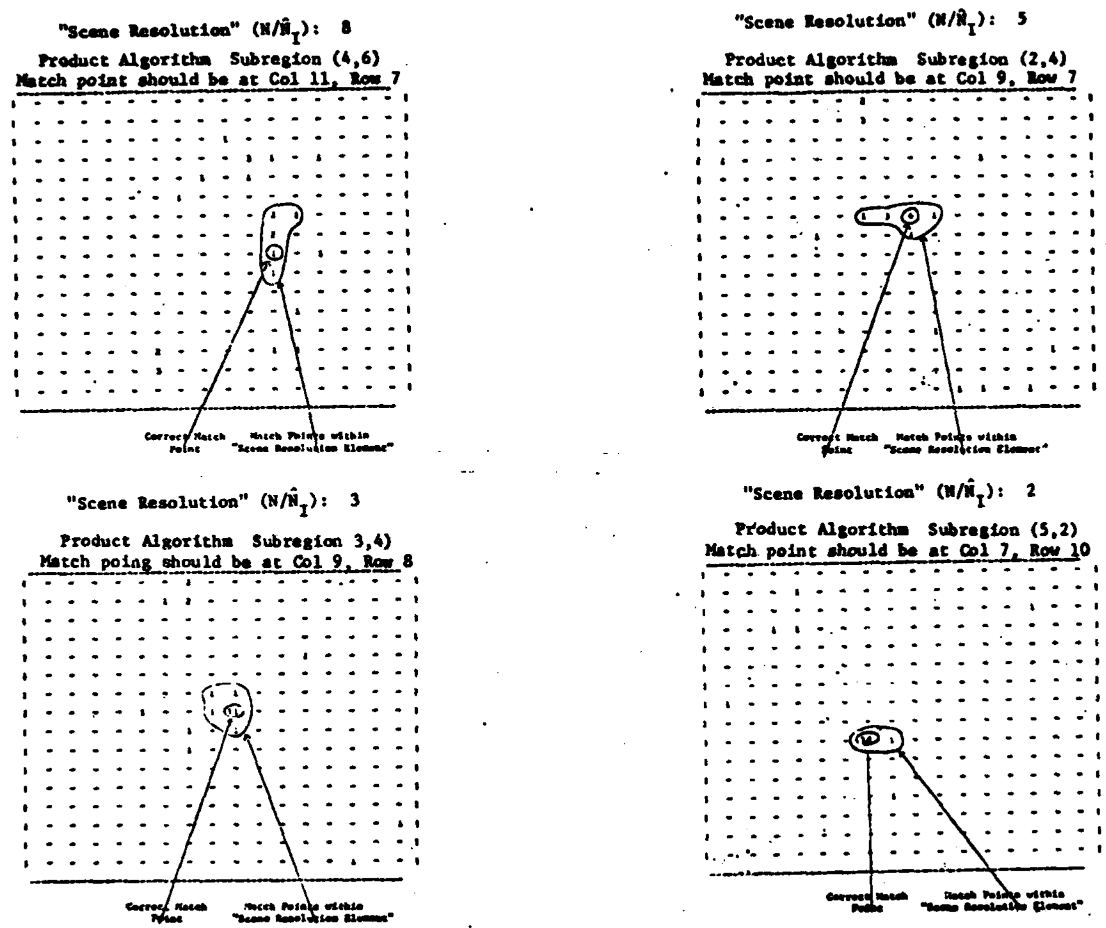


Fig. 10 — Accuracy of match prediction ("scene resolution")

(sensor resolution). As the "sensor resolution" is decreased, the correct match points will spread out over a larger area around the correct match point between the two maps. (The area size of this spread will roughly equal in pixels the "scene resolution.")

To test the segmenting process, several 5 × 5 subregions were selected from a map of an agricultural area. The three subregions consist of Case 1, a sensor map which is completely homogeneous; Case 2, a sensor map just slightly overlapping a second homogeneous area; and Case 3, a sensor map straddling the boundary between two homogeneous regions. Monte Carlo simulations were run for these regions for both an unprocessed* and a homogeneously segmented sensor and reference map. The match point locations and the calculated analytical parameters are shown in Fig. 11. For the homogeneous sensor map, Case 1, the results for both methods of correlation are almost identical with the variation, primarily due to different noise samples. As the degree of nonhomogeneity in the map increases, the acquisition basket or system accuracy degrades for the ordinary correlation case, while it remains essentially fixed for the homogeneously segmented case, as measured by the scene resolution parameter.

Geometric errors tend to spread out the correlation surface and thus degrade the overall system accuracy. Honeywell,† for the case of a two-dimensional image, has developed an iterative algorithm known as "address modification" for removing geometric warping between images. The basic concept is that geometric distortions between the reference and sensor scenes can be represented for coplanar scenes by an eight-parameter transformation. Honeywell has developed an algorithm which iteratively converges to a solution for these geometric parameters, so that one can remove the effects of geometric distortion from the image. This algorithm is useful in improving system accuracy once the acquisition problem of locating the general area of match between the two images has been solved. The case of three-dimensional images (i.e., cultural features such as buildings) is a more difficult problem to dewarp and requires storing the entire three-dimensional image of the target area.

---

*Ordinary correlation algorithm.

†J. Merchant, *Address Modification, Image Technology Program*, Vol. I; *Overview and Theory*, Vol. II, *Experimental Results*, Honeywell Electro-Optics Center, Lexington, MA, September 1978.

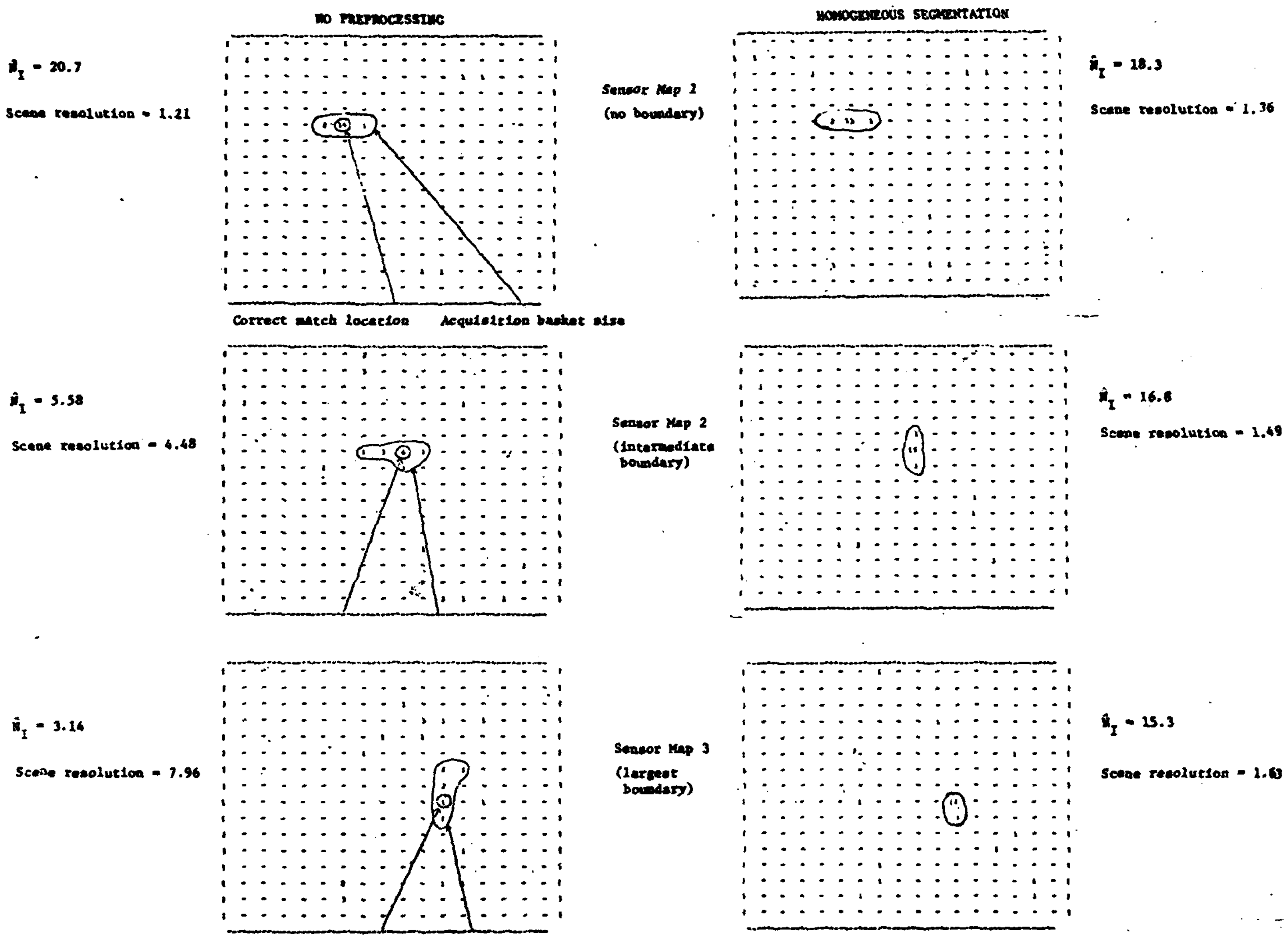


Fig. 11 — Comparison of no scene preprocessing with homogeneous scene segmentation Monte Carlo results

In summary, the following points can be made concerning the accuracy obtainable in a map matching system:

General Accuracy Statements

1. Accuracy can be qualitatively estimated by examining the slope of the correlation surface surrounding the true match peak and quantitatively estimated through use of the "scene resolution" concept.
2. Accuracy is dependent on both the interpixel correlation and the number of homogeneous regions in the scene.
3. Accuracy is most severely degraded by the presence of large homogeneous regions without structure within the scene, and by the introduction into the system of geometric distortions.

Methods for Improving Accuracy

4. Accuracy can be improved by the use of feature matching techniques (pure feature matching, feature matching correlation, or hybrid correlation) which homogeneously segment the scene.
5. Accuracy in the presence of geometric distortions can be improved by the reduction of the map size and by utilizing algorithms that dewarp the distortion between reference scene and sensed image.

IV. THE ACQUISITION PHASE OF MAP MATCHING

The acquisition phase is concerned primarily with obtaining a match location in the vicinity of the correct location and avoiding at all possible costs a false match; hence, the performance measure of interest is the probability of false match, P_F. The acquisition system design problem is illustrated in Fig. 12. Basically there are a number of system parameters such as sensor orientation, resolution, wavelength, and the flight geometry which can introduce errors into the system and which provide the basis for selecting the area in which the reference maps are located. Various parts of the system (preprocessing, scene selection, algorithm choice, and system verification) are then designed to accommodate the potential problem areas (errors and scene composition). The system design approach is sequential in nature. The first step of the design procedure is the preprocessing. Global errors, primarily geometric distortions, must be accommodated in the preprocessing of the acquisition phase, limiting the map size and grouping the elements. Also, the intensity level normalization plan must be formulated to accommodate anticipated gain changes and bias shifts. Preprocessing sets the stage for the scene selection process because it essentially determines the size and shape of the sensor image or subimages (depending on whether or not the scene is to be broken into segments).

With the size and shape of the sensor map governed by the anticipated geometric errors, the scene selection process must check the ensemble of all possible sensor images contained within the candidate reference areas for (1) a sufficient number of independent elements (to ensure that sufficient information is available to perform matching) and (2) intrascene spatial redundancy (to avoid as much as possible the checkerboard problem of obtaining many similar regions within a scene). Once the scene selection process has identified a reference area which has a sufficient number of independent elements and avoids the intrascene redundancy problem, the next step is the algorithm choice. The choice of general algorithm is dictated by the magnitude and type of errors (regional, local, and nonstructured) that are present in the

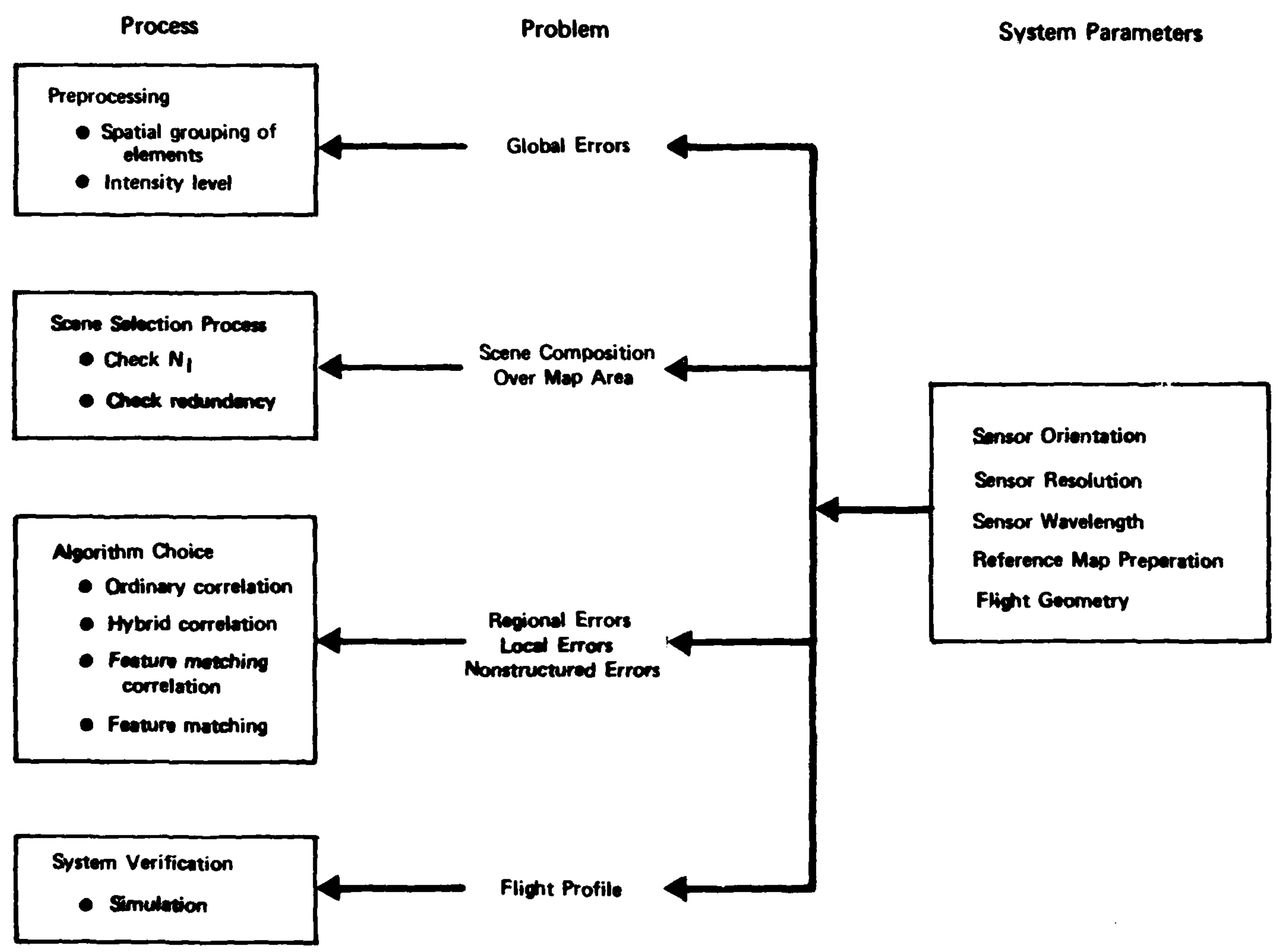


Fig. 12 — Acquisition system design

system. In the extreme case, if local errors are dominant (e.g., additive noise), then ordinary correlation-type algorithms are called for; if regional errors (e.g., contrast reversals) are dominant in the system, feature matching algorithms are the obvious choice. A different mix of these errors calls for a different choice of matching algorithm. Finally, the sensor and guidance systems must be verified by simulation to ensure a low P_F value.

The remainder of this section discusses each of the system design steps (preprocessing, scene selection, algorithm choice, and system verification) separately.

PREPROCESSING

The two major categories of preprocessing, as described previously, are intensity level modification and spatial grouping of the elements. Changes in gain and bias levels can alter the sensor signal level. If these errors are present in the system then the data must be modified (zero-meaned for bias level changes and normalized to unit variance for gain changes) to accommodate these types of errors.

Geometric-type global errors must be accommodated in the acquisition phase by reducing the number of pixels contained within the map to accommodate the maximum amount of distortion anticipated. In the accuracy phase, after one has located the general area which contains the correct match location, it is possible to use other techniques, such as "address modification,"[*] to remove geometric distortions. Two preprocessing methods for handling the geometric distortion problem are "spatial windowing" and "subarea correlation."

The concept of "spatial windowing," introduced by Fred Smith of SCI,[†] is a method for improving both the sharpness of the correlation peak and reducing the false fix probability. This concept consists of taking several different size sensor maps, all spatially centered. The largest sensor map or window about the center point will have the flattest correlation surface, while the smallest window will have the

---

[*] Honeywell.

[†] F. W. Smith et al., *Optimal Spatial Filters*, DARPA Contract DAAK 40-77-C-0113, System Control, Inc., Palo Alto, September 1978.

sharpest peak; however, because it has fewer elements, it will also have many sharp false peaks. The philosophy behind the concept is that the true peak should occur in the correlations associated with every window size; while false peaks may appear in the correlation surface of all window sizes, they will not show up at the same displacement position in the correlation surface. Therefore, by screening correlation peaks as a function of displacement position for all window sizes, one can possibly eliminate the false peaks and locate the true match location. One possible screening procedure would involve first setting all the negative correlation values in the correlation surface equal to zero and then multiplying at each displacement position the values of the correlation surface for each window size. The process of setting the negative correlation values equal to zero would eliminate the possibility of having the product of several large negative correlation values coming out to be a relatively large positive value. The true correlation peak should be a relatively high value, occurring at the same displacement position in all correlations; false peaks, not occurring at the same location, would have high values at one displacement position for one sensor map size offset by low correlation values for another sensor map at the same location. Thus, the multiplication processing of several correlation surfaces should cause the true peak to stand out and increase the accuracy with which it is located.

"Subarea correlation"* is another means of reducing the vulnerability of the system to false matches when geometric errors are present. In this concept, instead of matching one large map to another larger map, a number of smaller maps are selected from the reference map in such a manner that there is a high probability that several of them will be contained within the sensor map. These individual subareas are then correlated over the sensor map and the position of best match is determined for each subarea. Since the relative location of the

---

*G. Gerson et al., *Image Sensor Measurements Program: Volume 1, Multiple Subarea Bi-Level Correlation Scene Matching System*, Contract F-30602-77-C-0049, Hughes Research Laboratories, Malibu, California, June 1979.

subareas is known perfectly in the reference map, this information, combined with the positional alignment of the subareas in the sensor map, will enable the sensor map to be located relative to the reference map, even in the presence of geometric distortions in the scene. One of the key questions in this concept is how to pick the subareas. The subareas should be chosen such that (1) they are geometrically positioned so that multilateration of the subareas will reveal the location of a reference point in the map and the magnitude of any geometric errors in the scene, and (2) each subarea can be uniquely and accurately located. The accuracy criterion involves choosing subareas with a low "scene resolution" and avoiding subareas that have contained within them the shape of homogeneous regions repeated elsewhere in the scene.

"Spatial windowing" and "subarea correlation" are primarily designed to avoid the false match problem and identify the acquisition basket in which the true peak is expected to be located. These two techniques are also useful in the accuracy phase of matching; however, geometric dewarping techniques theoretically look more promising in accommodating distortion in two-dimensional imagery.

SCENE SELECTION

The subject of criteria for scene selection is almost a topic of its own. One must choose reference areas for which, for the ensemble of possible sensor maps contained within the reference area, there is (1) sufficient information for map matching and (2) a minimal amount of interscene spatial redundancy within the reference map boundary.

Various authors have suggested a number of measures to deal with the information content issue; however, no procedures have been proposed to deal with the spatial redundancy question. The three most relevant measures for information content are (1) the correlation length, (2) the scene resolution, and (3) the number of vertices associated with features in the scene (proposed by Hall*). The

---

*E. Hall and R. C. Gonzalez, *Scene Content Analysis, Measurement, Refinement, and Verification*, DARPA/SAMSO Contract F4701-77-C-0072, University of Tennessee, December 1978.

correlation length measure is used by many authors as a scene content measure. However, as pointed out previously, correlation length is a confusing term and can be taken to mean either of two different quantities. In the case of a completely homogeneous scene it is meant to be the degree of interpixel correlation. For the nonhomogeneous case it is dominated by the size and number of homogeneous regions in the scene and not by the interpixel correlation. The other major problem with this measure is that the correlation length can be computed for any number of directions around the correct match location so that there is an additional ambiguity as to whether one is dealing with the average correlation length, longest, shortest, etc.

A measure which attempts to overcome both deficiencies--definition and measurement--of correlation length is the "scene resolution" concept. Basically, the attempt is to estimate in a pseudo sense the number of independent elements in the scene. By dividing this number into the total number of scene elements, one obtains an estimate of the scene resolution. The procedure for calculating the scene resolution is explained in detail in an earlier Rand report.* Briefly, the basic approach in calculating the scene resolution is to assume a "statistically equivalent scene model," i.e., that the scene is completely homogeneous with all elements independent. Obviously this assumption is not true, but by making it one can use the simple relationship between the statistics of the correlation surface and the number of independent scene elements. Thus, by simply measuring the statistics of the correlation surface, one can work backwards to estimate for all scenes the scene resolution (N/N_I) using the statistically equivalent scene model. As shown in the previous two sections, this parameter does perform quite well in predicting (1) the size of the acquisition basket (the region around the correct match point in which correct matches are likely to fall), and (2) the width of the correlation peak (which is related to match accuracy).

---

*J. A. Ratkovic et al., *Estimation Techniques and Other Work on Image Correlation*, The Rand Corporation, R-2211-AF, September 1977.

One potential shortcoming of this approach is that it is a correlation-based technique and thus, by its nature, regions or features in the scene are weighted by the number of sensor elements contained within. In using a pure feature matching technique the homogeneous regions are generally weighted equally regardless of their size. Thus Hall's measure of the number of vertex points (N_V) of homogeneous regions contained within the scene may be a more appropriate measure of information content for map matching when pure feature matching algorithms are employed.

As pointed out in Section II, the relationship between the occurrence of false matches and the number of independent scene elements has been modeled for the noise failure mechanism but not for the spatial structure failure mechanism. Without a mathematical model (which would be extremely scene-dependent) directly relating the spatial structure of the scene to system performance, one can only speculate what measure might be indicative of a spatial structure failure.

Some researchers have proposed that the height of the secondary peaks in the correlation surface is indicative of the degree of congruence between the sensor image and some other area in the reference scene which may have similar characteristics. This quantity may not necessarily be a good measure of the repetitive spatial structure problem because high correlation may result from an unknown bias or gain change since standard correlation algorithms are global-type operators. One would prefer a measure more related to the underlying structure of the scene than to its global characteristics, which is what ordinary correlation algorithms work on.

The hybrid correlation algorithm provides a better handle on this repetitive scene structure problem. This algorithm assumes that the sensor scene has the same underlying structure as the reference map to which it is being compared. This algorithm should then give rise to secondary correlation peaks in areas where the repetitive structure problem is likely to occur.

Thus it appears that the scene resolution concept is an appropriate measure of scene content for correlation algorithms, whereas the number of vertices appears to be appropriate for feature matching algorithms. While these measures (at least scene resolution and probably the N_V measures) can be related to the probability of false fix for the simple noise failure case, there exists no such measure or model for the spatial repetition problem. Here we have speculated that the height of secondary correlation peaks (using the hybrid algorithm) may be a good approach in measuring the degree of spatial repetition in the reference map.

ALGORITHM SELECTION PROCESS

The choice of matching algorithm will depend on the nature and magnitude of the regional and local errors. Some analysis has been performed in relating nonstructured errors to changes in system performance. In general the algorithm choice is not strongly dependent on the nature of nonstructured errors. Nonstructured errors are best accommodated in the mission planning phase of the operation. By proper route planning obscuration and masking errors may be avoided, and by timing and weather planning it may be possible to reduce the diurnal and weather effects which can cause nonstructured errors. Thus nonstructured errors can be reduced by careful mission planning. Generally, any residual nonstructured errors cannot be adequately modeled, and thus one can only hope that they do not seriously degrade system performance.

The algorithm choice, then, in the extreme case of local errors only tends toward ordinary correlation, whereas in the other extreme (regional errors only) the algorithm tends toward pure feature matching. Because one is generally never confronted by an either-or situation (except in the case of terrain contour mapping, where there are primarily local errors), it is necessary to weigh the relative magnitude of local and regional errors present when deciding upon the choice of algorithm.

Let us first consider the differences between the various categories of correlation algorithms when only local errors (additive noise) are present. To examine the effect, we took several 10 × 10 element sensor maps from the center of 20 × 20 reference scenes in various parts of an Earth Resources Satellite map. To these sensor scenes, we added white Gaussian-distributed noise such that the S/N ratio was 0.5. The simulation consisted of creating 25 different noisy sensor images and matching the reference and sensed imagery for different categories of algorithms (feature matching correlation, hybrid, and ordinary correlation) and types of algorithms (product, MAD, and difference squared). Table 5 shows the number of independent elements estimated to be contained within the scene and the percent of successful matches (P_{SIM}) for each category and type of algorithm.

The homogeneous regions within the reference map boundary were defined manually. The homogeneous regions or features in the sensor image were also defined manually for the feature matching correlation algorithm. In the real world these regions must be extracted automatically so that the results for the feature matching correlation algorithm are, in a sense, an optimum case. In the real world, homogeneous regions are generally extracted through the use of edge operators, which do not perform well in the presence of local errors. Simulation results achieved for real-world scenes using pure feature matching approaches generally indicate that results closer to those achieved by the hybrid algorithm are obtainable when automated edge finding feature extraction techniques are used.[*]

In examining the simulation results, the "perfect" (homogeneous regions extracted from both the map and the sensor image without error) feature matching correlation algorithm is the best performer, followed closely by the ordinary correlation algorithm. The hybrid class of algorithm does not do nearly as well as the other two classes of algorithms when the product algorithm is used.[†] Among the types of algorithms used, the difference squared was definitely the best performer, primarily because there were no gain changes in the data and the product algorithm was normalized in the preprocessing for a gain change

---

[*] R. L. Kin, *Pattern Matcher Development Study*, DARPA Contract DAAK 40-77-C-0017, Rockwell International, Missile Systems Division, Anaheim, California, June 1978.

[†] This is because the hybrid algorithm is designed to accommodate both regional and local errors. In the absence of regional errors, it would be expected that ordinary correlation techniques (designed only for local errors) would work best.

Table 5

MONTE CARLO SIMULATION RESULTS FOR DIFFERENT TYPES OF HOMOGENEOUS PROCESSING

Reference Map: 20 × 20 Sensor Map: 10 × 10

				Simulation Results					
			Noise-Free Parameter	Product		MAD		Difference Squared	
Terrain Type	Region	Type of Algorithm[a]	$\hat{N}_I$	P_{SIM}	$P_c \pm \sigma$	P_{SIM}	$P_c \pm \sigma$	P_{SIM}	$P_c \pm \sigma$
Mountain	2	Ordinary Correlation	10.5	0.96	0.80 ± 0.05	0.96	0.88 ± 0.07	0.96	0.91 ± 0.06
Mountain	2	Hybrid	41.1	0.68	0.75 ± 0.07	0.92	0.97 ± 0.05	1.00	0.98 ± 0.04
Mountain	2	Feature Matching Correlation	63.2	1.00	0.99 ± 0.00	1.00	1.00 ± 0.00	1.00	1.00 ± 0.00
Suburbs	17	Ordinary Correlation	24.2	1.00	0.95 0.03	1.00	0.89 0.08	1.00	0.56 0.15
Suburbs	17	Hybrid	36.5	0.80	0.73 0.10	1.00	1.00 0.00	1.00	1.00 0.00
Suburbs	17	Feature Matching Correlation	48.6	1.00	0.98 0.00	1.00	.997 0.00	1.00	.997 0.00
Desert	10	Ordinary Correlation	36.9	1.00	0.97 0.03	1.00	.997 0.03	1.00	.991 0.03
Desert	10	Hybrid	36.9	1.00	0.97 0.03	1.00	.997 0.03	1.00	.991 0.03
Desert	10	Feature Matching Correlation	36.9	1.00	0.97 0.03	1.00	.997 0.03	1.00	.991 0.03
Desert	6	Ordinary Correlation	20.98	0.96	0.94 0.03	1.00	0.86 0.10	0.96	.874 0.09
Desert	6	Hybrid	27.31	0.68	0.85 0.05	0.96	0.84 0.13	0.96	0.85 0.14
Desert	6	Feature Matching Correlation	31.2	1.00	0.96 0.03	1.00	.994 0.00	1.00	.997 0.00
Agricultural	12	Ordinary Correlation	5.61	0.76	0.65 0.04	0.80	0.76 0.08	0.84	0.73 0.10
Agricultural	12	Hybrid	17.35	0.36	.677 0.10	0.12	.886 0.08	0.84	.892 0.08
Agricultural	12	Feature Matching Correlation	40.97	1.00	.971 0.03	1.00	0.99 0.00	1.00	0.99 0.03

[a]The processing refers to whether or not the sensor and/or the reference maps were segmented into homogeneous regions.

error. Had a gain change occurred, the product (normalized) algorithm would have been the superior performer.

The simulation results also indicated that, with the exception of Region 12, most of the scenes correlated quite well when considering the magnitude of the noise error. Thus, for most of these cases, the few false fixes that did occur were due primarily to a noise failure mechanism. The unusual performance of the agricultural scene (Region 12) might lead one to suspect an intrascene spatial redundancy failure mode, which was indeed the case.

Figure 13 shows the pixel-by-pixel breakdown of the homogeneous segmentation process (indicated by region numbers) and the location of the 25 match points for the simulation runs where only the reference map was broken into homogeneous regions. Two different map comparison positions are outlined in the figure--the correct match sensor location, taken from the center of the scene, and a map comparison position in the upper left-hand portion of the scene. The relative match location in the simulation runs is indicated in the figure. Examination of the two map displacement positions reveals an almost identical spatial pattern of the homogeneous regions for both displacement positions. This repetition of the spatial pattern led to a large number of false fixes for the difference squared algorithm at the repeated position. For the product algorithm, no false fixes occurred at the pattern repeat position; however, a large number did occur at nearby locations.

The Appendix contains intensity level and region maps for these scenes, as well as the autocorrelation surfaces using all three algorithms. The autocorrelation surface using ordinary correlation shows for Region 12 a high correlation coefficient in the displacement position where false matches did occur. The hybrid correlation surface shows a secondary peak at this location; while the correlation value was not as high (0.6 versus 0.8 for the ordinary correlation), it is definitely easier to locate this intrascene redundancy problem from the hybrid algorithm as opposed to the ordinary correlation algorithm. The feature matching correlation algorithm did not yield (as indicated by the correlation surface) a great deal of information concerning the magnitude and location of the intrascene redundancy problem. In

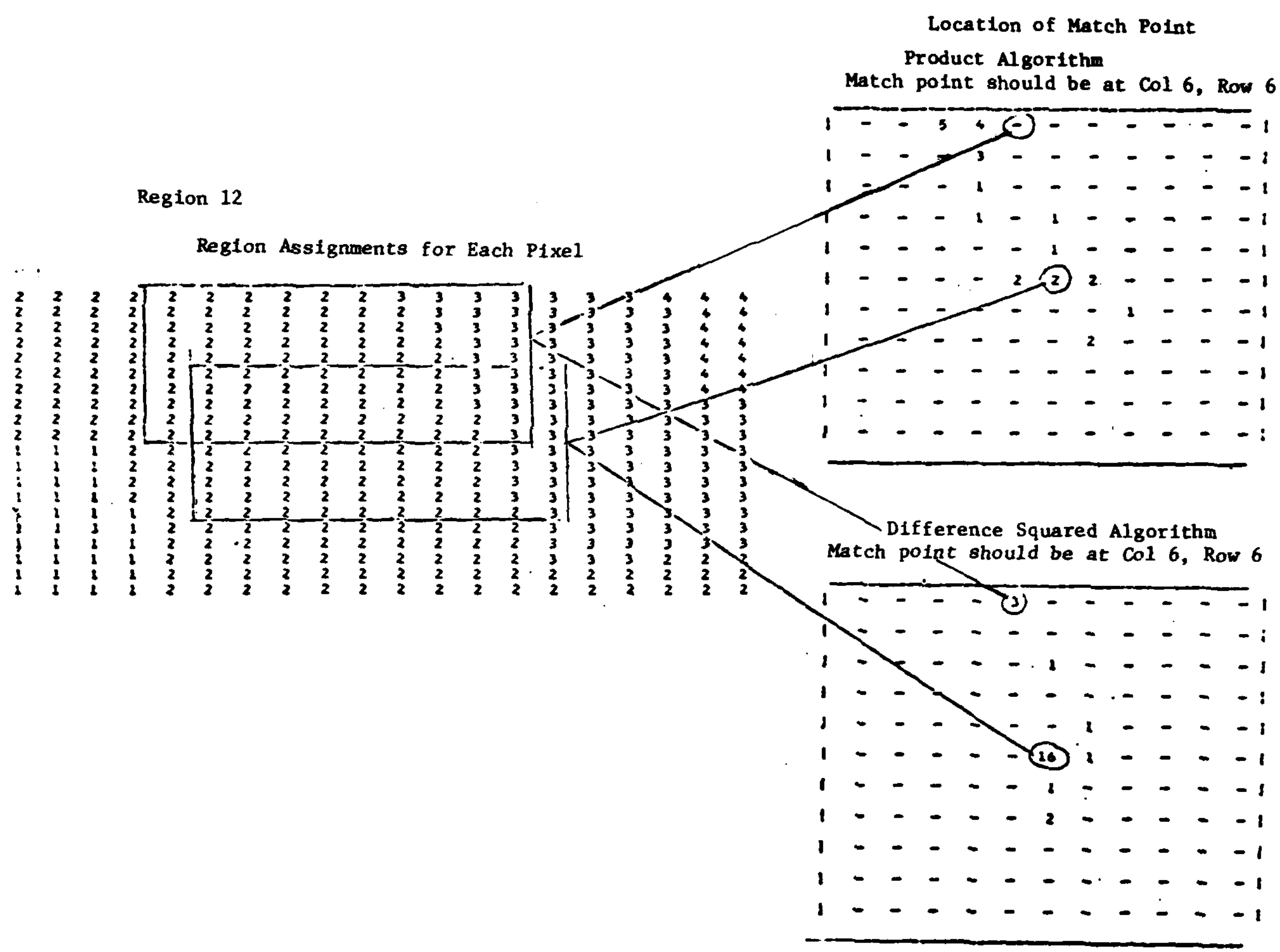


Fig. 13 — The effect of region redundancy on probability of correct match

Region 2, the hybrid correlation algorithm also revealed a secondary peak in the general vicinity where a false match did occur using all three ordinary correlation algorithms (MAD, product, and difference squared). Thus it appears, based on this limited sampling of data, that the hybrid correlation algorithm can play a significant role in determining the magnitude and location of the spatial scene redundancy problem during the scene selection process.

To further test the suitability of an algorithm to tolerate local error, another simulation identical to the first was run using a small sensor map (5 × 5). The smaller sensor map with fewer elements makes the system more susceptible to both noise and spatial structure failure modes. For this particular simulation, only the ordinary correlation algorithm (scene not homogenized) and the feature matching correlation algorithm (scene homogenized) were used. With the smaller map, the ordinary correlation algorithm generally does slightly better (in terms of choosing the correct match point more frequently), as is indicated in Table 6, than the "perfect" feature matching correlation algorithm. The major exception is a region where there is a large scene redundancy problem (desert region 5, subregion (6,1)).

Thus, if one could screen out the scenes in the selection process where spatial redundancy is likely to be a problem, the ordinary correlation algorithm definitely does as well as the "optimum" or "perfect" feature matcher in the presence of large local errors. When one considers the degradation in performance encountered in going from the optimal to the real-world feature matching algorithms, one is likely to expect performance significantly below that of the ordinary correlation algorithms and close to that obtained using the hybrid class of algorithms.

To determine the change in system performance due to regional errors interacting with the three different categories and types of algorithms described previously, we ran an experiment to test the effects of such errors. In an attempt to place regional errors into the correlation process, we decided to see the effect of changing the mean values of the "intensity" levels in the homogeneous regions of the scene. For this experiment a sensor map (20 × 20) was chosen with a

Table 6

SIMULATION RESULTS FOR OTHER TERRAIN TYPES

Sensor Map: 5 × 5 Elements   Reference Map: 20 × 20 Elements

Terrain Type	Region/ Subregion	Scene Homog- enized?	Noise-Free Parameter $\hat{N}_I$	Monte Carlo Results: Product P_{SIM}	Product $\hat{P}_c \pm \sigma$	MAD P_{SIM}	MAD $\hat{P}_c \pm \sigma$	Difference Squared P_{SIM}	Difference Squared $\hat{P}_c \pm \sigma$
Desert	6/(6,1)	No	5.5	.20	.46 ± .04	.12	.64 ± .14	.16	.45 ± .16
Desert	6/(6,1)	Yes	16.5	.72	.59 ± .09	.68	.38 ± .17	.76	.12 ± .10
Desert	6/(4,5)	No	6.9	.48	.48 ± .05	.48	.77 ± .15	.64	.73 ± .17
Desert	6/(4,5)	Yes	10.2	.52	.52 ± .06	.44	.53 ± .17	.60	.28 ± .15
Desert	6/(3,3)	No	8.0	.52	.50 ± .08	.52	.82 ± .14	.56	.75 ± .18
Desert	6/(3,3)	Yes	20.2	.72	.61 ± .10	.64	.67 ± .22	.64	.54 ± .25
Desert	6/(1,3)	No	9.5	.56	.53 ± .09	.52	.78 ± .17	.60	.67 ± .22
Desert	6/(1,3)	Yes	10.0	.48	.50 ± .08	.72	.82 ± .15	.76	.72 ± .21
Mountains	4/(5,6)	No	3.8	.52	.34 ± .04	.56	.60 ± .14	.48	.46 ± .18
Mountains	4/(5,6)	Yes	17.2	.52	.55 ± .10	.48	.75 ± .16	.60	.70 ± .21
Mountains	4/(4,4)	No	8.2	.76	.49 ± .08	.64	.52 ± .16	.76	.39 ± .22
Mountains	4/(4,4	Yes	15.5	.56	.55 ± .07	.72	.76 ± .16	.68	.72 ± .19
Mountains	4/(2,1)	No	16.9	.72	.53 ± .14	.76	.23 ± .15	.80	.06 ± .1
Mountains	4/(2,1)	Yes	19.2	.76	.60 ± .11	.68	.78 ± .18	.72	.74 ± .23
Mountains	4/(5,1)	No	33.2	.84	.64 ± .15	.92	.08 ± .05	.96	.00 ± .0
Mountains	4/(5,1)	Yes	21.5	.68	.59 ± .13	.52	.67 ± .21	.72	.50 ± .26
Suburban	17/(5,3)	No	7.8	.60	.48 ± .07	.76	.16 ± .09	.76	.001 ± .0
Suburban	17/(5,3)	Yes	19.1	.72	.58 ± .11	.60	.52 ± .26	.68	.08 ± .12
Suburban	17/(2,5)	No	11.8	.64	.50 ± .08	.56	.62 ± .26	.68	.23 ± .23
Suburban	17/(2,5)	Yes	22.9	.48	.55 ± .09	.40	.34 ± .16	.60	.06 ± .23
Suburban	17/(4,6)	No	15.3	.64	.56 ± .11	.60	.19 ± .15	.76	.01 ± .0
Suburban	17/(4,6)	Yes	20.4	.60	.57 ± .10	.72	.55 ± .25	.22	.20 ± .20
Suburban	17/(1,3)	No	22.2	.72	.56 ± .09	.76	.38 ± .19	.72	.06 ± .14
Suburban	17/(1,3)	Yes	23.3	.48	.58 ± .13	.52	.32 ± .16	.52	.04 ± .01

larger number of homogeneous regions (mountain area, region 4) and the mean level of each homogeneous region was changed by a random amount. The magnitude of the level change was drawn from a zero-mean Gaussian distribution with three different standard deviations chosen to be 25, 50, and 100 percent of the dynamic range of intensity values in the scene. Three different algorithms (the normalized product, the difference squared with the mean intensity value subtracted out, and the difference squared algorithm) and three different processing schemes (both sensor and reference maps homogeneously segmented, only the reference map segmented, and no segmentation) were utilized. Additionally, a small amount of noise was added to each pixel in the scene. The results in Table 7 give the percent of successful correlations (out of 25), P_{SIM}, for each run using the different algorithm categories and types. Since we are using the "perfect" feature matching correlation algorithm, we would not expect any change in performance with change in level, and the results so indicate. On the other hand, there is a definite degradation in P_{SIM} for the ordinary correlation cases for all types of algorithms with increasing changes among homogeneous levels in the scene. The hybrid algorithms, while generally having performance somewhat below that of the "perfect" feature matching algorithms, essentially do not degrade with increasing regional error.

For the unprocessed case, the difference squared and normalized product started off at the 25 percent intensity level change performing about equally well; however, as the magnitude of the level change reached 50 percent and beyond, the normalized product algorithm outperformed both versions of the difference squared algorithm. Thus, if there are mean intensity level changes in the scene on the order of 50 percent of the intensity difference between regions of the scene, and if no homogeneous processing is performed, the normalized product algorithm should be utilized. If either the reference and/or reference and sensor maps are homogeneously segmented, then the difference squared algorithm (zero-meaned) should be used, assuming that gain changes are not anticipated.

Table 7

SIMULATION RESULTS WITH LEVEL CHANGES BETWEEN HOMOGENEOUS REGIONS
Mountain Area
20 × 20 Sensor Map
40 × 40 Reference Map

Process[a]	Algorithm	Magnitude of Level Change[b]		
		25 Percent	50 Percent	100 Percent
		P_{SIM}[c]	P_{SIM}	P_{SIM}
0	Normalized Product	0.92	0.88	0.52
0	Difference Squared (Zero-meaned)	0.88	0.68	0.48
0	Difference Squared	0.88	0.56	0.40
1	Normalized Product	0.72	0.72	0.68
1	Difference Squared (Zero-Meaned)	0.96	1.0	1.0
1	Difference Squared	0.92	0.64	0.40
2	Normalized Product	1.0	1.0	1.0
2	Difference Squared (Zero-Meaned)	1.0	1.0	1.0

[a]Process refers here to the degree of homogeneous segmentation, with a zero indicating ordinary correlation, a one indicating that only the reference map was segmented, and a two indicating that both maps were segmented.

[b]In the simulation runs a small amount of additive noise was added to each pixel and a constant random value was added to each region. The magnitude of the constant value was determined by calling a random number. The distribution associated with the random number had a standard deviation equivalent to 25, 50, and 100 percent of the range of intensity values in the scene.

[c]P_{SIM} indicates the percent of correlations out of 25 that fall within an area the size of the scene resolution about the correct match location.

Let us examine the magnitude of the regional errors associated with various sensor types. Table 8* gives a rough guideline of the magnitude of the regional errors one would anticipate for each of the sensor types. These numbers represent general guidelines and there a number of caveats. The percentage error for the passive visible/ near IR sensors assumes that there is some means of calibrating the system onboard in real time to skylight illumination. The middle IR and far IR wavelengths do not operate at dawn or dusk when thermal crossovers are likely to occur, and it is assumed that one has a reference map that differentiates between night and day operations; otherwise the regional variations can be as high as a few hundred percent. The passive microwave is very material-dependent, with high emissivity material (such as grass and soil) behaving similarly to the middle and far IR wavelengths; the low to moderate emissivity materials can be fairly stable in signature, with the possible exception imposed by cloud cover. Active microwave signatures can vary on the same order as the middle and far IR signatures. Range signature errors such as those associated with TERCOM are generally quite small.

Based on this first-order signature analysis, the magnitude of the regional errors is small enough for the active/near IR wavelengths and for the range sensors so that ordinary correlation techniques can perform the matching task. It may also be possible to use ordinary correlation for a passive visible/near IR system. For all other wavelengths it appears that one must move away from the ordinary correlation approach and incorporate some form of feature matching or hybrid correlation algorithm into the matching process to compensate for regional errors. It may, however, still be possible to use ordinary correlation algorithms over a broader range of sensor wavelengths by carefully screening the reference area with respect to such parameters as emissivity, thermal inertia, reflectivity, etc.

To summarize, ordinary correlation algorithms look attractive for accommodating local errors as long as the scene spatial redundancy

---

*Prepared by Lloyd Mundie of Rand and Ed Conrow of the Aerospace Corporation.

Table 8

REGIONAL ERRORS VERSUS SENSOR TYPE

Sensor Type	Percent Regional Error[a]
Active visible/near IR	10 to 20
Passive visible/near IR[b]	20 to 40
Middle IR/far IR	Greater than 50
Passive microwave	30 to 50
Active microwave	Greater than 50
Range sensors	5

[a]The average difference between the actual mean intensity level difference among regions and the predicted intensity level difference among regions divided by the actual intensity range spread among regions.

[b]Assumes sensor calibrated by skylight illumination.

problem can be avoided in the scene selection process. Ordinary correlation algorithms degrade significantly in the presence of regional errors, especially when the magnitude of the mean intensity level change is of the order of 50 percent or more of the difference in intensity levels between regions. Feature matching correlation algorithms look attractive for both regional and local errors if the homogeneous boundaries can be extracted from the sensed image.

In this Note we have been working with perfect feature matching algorithms (i.e., we have been able to correctly identify the homogeneous regions in the sensor map). In the real world this is generally difficult because of local (e.g., noise) and nonstructural (e.g., shadows) errors. In addition, there is a considerable amount of computer software and hardware required to perform this feature extraction process in near real time.

Because it does accommodate regional errors, the hybrid algorithm offers three major advantages. First, it is not subject to the problems of extracting features from the sensed image which pure feature matching algorithms are associated with. Second, it can accommodate regional errors which can cause false matches in ordinary correlation. Third, this algorithm does not require the extensive computer hardware and software of the feature matching algorithms. The only major drawback of the algorithm is that it appears to have difficulty operating in a very low S/N ratio (< 1) environment. In general this drawback is not serious if the entire system is designed properly. It appears that, due to the nature of the feature extraction problem using edge methods, alternative statistical approaches need to be developed and tested.

V. SUMMARY AND CONCLUSIONS

This Note has described the image matching process as a two-phase process: the first phase is acquisition of the correct match area and the second is accurate location of the match point. The major reason for the failure of the system to acquire is due to a combination of noise plus interscene redundancy (e.g., checkerboard); the latter problem is extremely difficult to model. Accuracy depends on two components of the scene structure--the size and magnitude of homogeneous regions in the scene and the interpixel correlation (expressed in terms of independent scene elements)--and the amount of geometric distortion present.

Accuracy can be improved by using a hybrid or feature matching algorithm which segments the scene into homogeneous regions. This segmentation significantly sharpens the correlation. The residual spread in the correlation peak can be attributed to interpixel correlation. For coplanar scenes, geometric distortions between the reference and sensor scenes can be represented by an eight-parameter transformation. Honeywell has developed an algorithm which iteratively converges to estimates of these geometric parameters, so that one can remove the effect of geometric distortion from the image. Thus, by selecting algorithms of the feature matching type, and by incorporating an algorithm for removing distortion, it is possible to improve match accuracy.

The acquisition problem, described in Fig. 12, consists of determining the preprocessing requirements, developing scene selection criteria, choosing an algorithm, and verifying the system via a simulation. As indicated in this figure, the first problem is global errors, which are generally accommodated by either normalizing the intensity level or by spatially grouping the scene elements to reduce the susceptibility of the matching process to geometric distortion.

The scene selection process requires that two criteria be met. The first is that a sufficient amount of independent information be contained in the map. A number of methods have been proposed to measure the independent information contained within the scene. The correlation length appears to be a poor measure because of the ambiguity associated with the term. The number of "independent scene elements" appears to be a good measure for correlation processes, while the "number of vertices" appears appropriate for pure feature matching processes. The second scene selection process of importance is the avoidance of interscene redundancy (e.g., checkerboard patterns). The height of secondary correlation peaks using ordinary correlation does not appear to be as good a measure of scene redundancy as the height of secondary peaks using the hybrid algorithm. This hybrid class of algorithm assumes that at each displacement position the sensor image is segmented into homogeneous regions in an identical manner to the portion of the reference map against which it is being compared. Thus, this class of algorithm emphasizes the spatial structure of the scene and the few simulation results acquired to date indicate that secondary peaks on the autocorrelation surface associated with the hybrid algorithm are places where false matches are likely due to interscene redundancy.

Finally, in the acquisition process, an algorithm must be chosen from the generic class of ordinary correlation, hybrid correlation, feature matching correlation, and feature matching such that it can accommodate the numbers of regional, local, and nonstructured errors that are anticipated. If only local errors are anticipated (e.g., in the TERCOM navigation system), ordinary correlation algorithms are appropriate, whereas if regional errors dominate, a feature matching or hybrid algorithm is demanded. Most real-world scenes have both regional and local errors superimposed. If the magnitude of the variation in the mean intensity levels between homogeneous regions in the area (that can be accounted for in the signature prediction) exceeds in value 50 percent of the intensity level difference between regions, then one is forced to use a feature matching algorithm, with the hybrid algorithm looking like an attractive alternative to avoid the near-real-time feature extraction process in the sensed image while at the same time being able to deal with regional errors.

Appendix

REGION MAPS AND CORRELATION SURFACES FOR ORDINARY CORRELATION, HYBRID CORRELATION, AND FEATURE MATCHING CORRELATION ALGORITHMS

TERRAIN [illegible](...,MATR,DSRT,SMRG)= 2

REGION 4 USED FOR REFERENCE SCENE

11.	6.	8.	8.	7.	7.	8.	8.	9.	12.	9.	8.	6.	8.	9.	7.	11.	9.	6.	5.
10.	7.	8.	8.	7.	8.	10.	9.	7.	9.	8.	7.	6.	6.	5.	7.	11.	9.	8.	8.
7.	9.	11.	9.	9.	10.	11.	9.	9.	7.	7.	6.	7.	10.	12.	14.	15.	11.	10.	14.
9.	10.	10.	8.	10.	7.	7.	7.	7.	5.	7.	10.	15.	17.	17.	17.	19.	15.	15.	17.
10.	9.	10.	10.	9.	9.	8.	11.	14.	15.	16.	17.	20.	21.	20.	17.	18.	18.	14.	18.
9.	9.	12.	15.	15.	15.	14.	19.	20.	19.	17.	18.	21.	22.	20.	16.	19.	17.	11.	18.
15.	13.	14.	18.	18.	18.	17.	19.	20.	19.	13.	17.	20.	20.	18.	17.	18.	10.	11.	17.
16.	12.	15.	20.	19.	17.	15.	20.	20.	14.	9.	17.	20.	20.	17.	16.	12.	10.	12.	18.
14.	13.	21.	22.	20.	16.	16.	23.	17.	10.	17.	22.	22.	21.	18.	12.	8.	9.	18.	19.
10.	15.	20.	20.	19.	16.	16.	20.	15.	16.	20.	21.	19.	20.	16.	8.	10.	18.	20.	20.
13.	14.	19.	20.	17.	19.	15.	17.	18.	16.	21.	21.	19.	17.	17.	10.	12.	18.	20.	20.
12.	14.	16.	17.	17.	16.	15.	19.	17.	17.	20.	18.	15.	13.	13.	13.	17.	18.	17.	17.
12.	13.	17.	19.	20.	19.	17.	20.	16.	18.	16.	9.	5.	7.	8.	10.	8.	9.	11.	10.
20.	17.	12.	16.	19.	17.	15.	18.	19.	15.	8.	6.	7.	9.	8.	7.	7.	11.	11.	8.
17.	12.	15.	22.	22.	19.	16.	22.	20.	14.	8.	10.	8.	9.	8.	9.	11.	12.	8.	8.
12.	13.	15.	21.	20.	19.	17.	16.	6.	5.	3.	4.	4.	6.	7.	10.	11.	9.	5.	6.
15.	13.	18.	20.	19.	19.	16.	13.	7.	5.	4.	3.	3.	4.	7.	8.	10.	10.	8.	6.
13.	15.	19.	21.	21.	18.	14.	7.	5.	4.	5.	5.	7.	7.	7.	14.	15.	16.	15.	14.
17.	16.	16.	19.	19.	17.	12.	6.	6.	6.	13.	18.	15.	14.	18.	17.	17.	19.	18.	20.
16.	12.	15.	17.	17.	14.	9.	7.	7.	10.	20.	19.	13.	14.	15.	16.	17.	17.	17.	19.

REGION NUMBERS FOR REFERENCE SCENE

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	1	2
1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
1	1	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	4	2
3	3	3	2	2	2	2	2	2	2	4	2	2	2	2	2	2	4	4	2
3	3	3	2	2	2	2	2	2	4	4	2	2	2	2	2	4	4	4	2
3	3	2	2	2	2	2	2	2	4	2	2	2	2	2	4	4	4	2	2
3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	2	2	2
3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	2	2	2
3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5
2	2	3	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5
2	3	3	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5
3	3	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	5
3	3	2	2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	5
3	3	2	2	2	2	2	5	5	5	5	5	5	5	5	6	6	6	6	6
2	2	2	2	2	2	2	5	5	5	6	6	6	6	6	6	6	6	6	6
2	2	2	2	2	2	5	5	5	5	6	6	6	6	6	6	6	6	6	6

Fig. A-1 — Region 2 intensity level and region map

TERRAIN TYPE(AGRI,MNTJ,DSRT,SBRB)= 2

REGION 4 USED FOR REFERENCE SCENE

SCRT(NR,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 16.35999, VARIANCE = 17.89087

Ordinary Correlation Algorithm

PRCD. ALGORITHM: NORMALIZED? (0=NC,1=YES) = 1

-0.35594	-0.30610	-0.26315	-0.24590	-0.28546	-0.29285	-0.21734	-0.06725	0.02578	0.06177	0.02169
-0.24201	-0.18756	-0.17187	-0.23910	-0.31047	-0.27705	-0.13318	0.01020	0.08695	0.07815	-0.01230
-0.16915	-0.15384	-0.21927	-0.31281	-0.30891	-0.16111	0.02097	0.13192	0.14361	0.04647	-0.09697
-0.18120	-0.15192	-0.18296	-0.18002	-0.04796	0.21710	0.37128	0.39565	0.28361	0.13580	0.00283
-0.14724	-0.01334	0.02257	0.08079	0.32387	0.70520	0.71373	0.50595	0.31002	0.18351	0.13444
-0.02580	0.18311	0.23199	0.36356	0.70373	0.99997	0.70714	0.42215	0.30816	0.25888	0.24229
0.15256	0.30380	0.38707	0.56212	0.76175	0.75733	0.45437	0.27719	0.21332	0.19812	0.25287
0.25335	0.42454	0.56571	0.67920	0.70519	0.60487	0.37839	0.23260	0.16414	0.17664	0.26627
0.44582	0.62181	0.70258	0.67450	0.59687	0.46614	0.25629	0.13132	0.07583	0.08887	0.15392
0.56995	0.67210	0.63680	0.49684	0.35267	0.19338	0.03807	-0.01104	-0.03950	-0.07285	-0.06555
0.57517	0.57312	0.41817	0.20658	0.01567	-0.10157	-0.15046	-0.14860	-0.22108	-0.28103	-0.26117

HALF POINTS (COL,ROW): (7.73, 6.00), (6.00, 8.76), (4.40, 6.00), (6.00, 4.58),

SCENE RESOLUTION IS 9.549

MATCH AT COL 6, ROW 6, PHIM(0) = 0.99997

PMEANJ	PVARJ	QI	JI	RHO	VAR(0)	XARG	PCE
0.16	0.10	16.34	10.47	3.09	0.19		

P-C	XARG	K	A	B	NOTE: XARG=A(K-B)
0.853	-1.051	1.750	0.707	3.236	

NO NOISE: P-C ARGUMENT = -1.051
S/N = 0.50: XARG = 0.103, P-C = 0.541

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-2 — Region 2 correlation surface—ordinary correlation

TERRAIN TYPE(AGRI,NRLA,DSRT,.BRB)= 2

REGION 4 USED FOR REFERENCE SCENE

SQRT(NR,N,M),Q= 20 10 11 120. S/N=******* NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 16.35999, VARIANCE = 17.89087

Hybrid Correlation Algorithm

PROD. ALGORITHM; NORMALIZED? (0=NO,1=YES) = 1

-0.01336	-0.03107	-0.11656	-0.12548	-0.15493	0.00852	-0.09090	-0.03459	0.04846	0.15037	0.02581
0.08664	0.04989	0.00245	-0.08944	-0.10041	-0.10057	-0.18547	0.01331	0.11893	0.11628	0.01705
0.11670	0.03387	-0.05641	-0.12170	-0.06693	0.00844	0.04628	0.16210	0.16663	0.08737	-0.00565
-0.01792	0.05630	-0.04307	-0.07100	-0.05313	0.26005	0.21709	0.30286	0.15071	-0.04017	-0.10158
0.05291	0.13067	-0.02191	-0.16694	0.00107	0.45795	0.39137	0.26535	-0.00699	-0.13031	-0.01358
0.07432	0.25467	0.04583	-0.09330	0.17950	0.99996	0.38113	-0.04631	-0.20220	-0.08976	-0.04704
0.07789	0.06674	-0.05450	-0.15310	0.14789	0.40960	-0.11321	-0.39228	-0.31393	-0.22758	-0.15604
0.10687	0.07210	0.09236	0.08617	0.21314	0.31007	-0.06485	-0.26685	-0.20324	-0.07458	-0.08139
0.21997	0.29363	0.23217	0.15410	0.20976	0.19389	-0.11536	-0.21117	-0.09658	-0.06831	-0.03110
0.30668	0.32445	0.22386	0.13578	0.11820	0.13458	-0.06548	-0.10211	0.05091	0.10467	0.04174
0.23761	0.23342	0.05050	0.02784	-0.02321	0.03117	-0.03304	0.01674	0.12139	0.06351	0.00607

HALF POINTS (COL,ROW): (6.31, 6.00), (6.00, 6.85), (5.39, 6.00), (6.00, 5.08),

SCENE RESOLUTION IS 2.431

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99996

PMEANJ	PVARJ	QI	NL	RHO	VAR(0)	XARG	PCE
0.04	0.02	53.97	41.14	1.56	0.05		

P-C	XARG	K	A	B
0.998	-2.956	2.233	0.707	6.414

NOTE: XARG=A(K-B)

NO NOISE: P-C ARGUMENT = -2.956
S/N = 0.50: XARG = 1.273, P-C = 0.898

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-3 — Region 2 correlation surface—hybrid correlation

TYPE AIR TYPE(AGRI,MNTN,DSRT,SHPB)= 2

REGION 4 USED FOR REFERENCE SCENE

SENTINEL,R,M),C= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SUBREGION	MEAN	VARIANCE OF SENSOR SCENE
2	15.16667	4.63501
3	14.50000	3.25000
4	11.50000	4.25000
5	8.26667	3.76530

Feature Matching Correlation Algorithm

PROC. ALGORITHM: NORMALIZED? (0=NO,1=YES) = 1

-0.07192	-0.13637	-0.10962	-0.17076	-0.22285	-0.00402	-0.06598	-0.02106	0.01375	0.10326	-0.09427
-0.06672	-0.03470	-0.09094	-0.05176	-0.17726	-0.01956	-0.06784	0.03936	0.08101	-0.04364	-0.05117
-0.13000	-0.04037	-0.03356	-0.17775	-0.29067	-0.03462	-0.08549	-0.07946	-0.03812	-0.07491	-0.10488
-0.00627	0.17034	0.05063	-0.22562	-0.13701	0.18052	0.03451	0.11231	0.05071	-0.11084	-0.14189
-0.03428	0.04920	-0.10000	-0.34044	-0.08930	0.35555	0.23067	0.01104	-0.07602	-0.15315	-0.05345
0.19860	0.22677	-0.01650	-0.01996	0.21597	0.99996	0.28084	0.06624	-0.03190	0.07636	-0.00223
0.11514	-0.01417	-0.12755	-0.20544	0.11234	0.23028	-0.20420	-0.36852	-0.20589	-0.14231	-0.15889
0.13266	-0.01951	-0.02508	-0.07171	-0.01956	0.13405	-0.11494	-0.22511	-0.04756	0.00959	-0.07544
-0.00613	-0.08367	-0.16402	-0.03093	-0.07736	0.02175	-0.17027	-0.18086	-0.09076	-0.11094	-0.13864
0.00750	-0.00052	0.05016	0.10747	0.04568	0.12438	-0.05297	-0.02577	-0.02778	0.10521	0.10643
0.02624	0.09305	0.13263	0.13797	0.07074	0.11615	0.04230	-0.00091	-0.03332	0.05064	0.07075

HALF POINTS (COL,ROW): (6.70, 6.00), (6.00, 6.65), (5.36, 6.00), (6.00, 5.22),

SCENE RESOLUTION IS 1.582

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99996

PMEANJ	PVARJ	CI	NI	RHO	VAR(J)	XARG	PCE
-0.02	0.02	79.12	63.22	1.26	0.03		

P-C	XARG	K	A	B	NOTE: XARG=A(K-B)
1.000	-3.941	2.377	0.707	7.951	

NO NOISE: P-C ARGUMENT = -3.941
S/N = ...: XARG = 1.917, P-C = 0.972

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-4 — Region 2 correlation surface—feature matching algorithm

TERRAIN TYPE(AGRI,MNTN,DSRT,SEA)= 4

REGION 17 USED FOR REFERENCE SCENE

10.	12.	11.	11.	12.	13.	13.	11.	11.	12.	10.	11.	10.	13.	12.	11.	12.	13.	12.	12.
11.	11.	12.	12.	11.	12.	12.	12.	12.	13.	12.	12.	10.	11.	12.	13.	12.	11.	11.	12.
11.	11.	11.	11.	13.	15.	13.	11.	13.	18.	13.	10.	10.	12.	12.	11.	12.	11.	12.	13.
12.	13.	11.	9.	11.	14.	12.	14.	17.	15.	14.	12.	9.	12.	13.	11.	9.	10.	11.	12.
11.	12.	10.	12.	11.	13.	13.	12.	11.	14.	14.	14.	11.	10.	13.	15.	12.	10.	10.	11.
10.	11.	11.	11.	12.	14.	14.	13.	12.	12.	13.	12.	12.	11.	12.	24.	14.	8.	9.	10.
10.	13.	12.	11.	11.	11.	14.	19.	15.	12.	13.	10.	8.	8.	9.	13.	13.	11.	12.	12.
11.	13.	11.	10.	11.	12.	11.	11.	12.	12.	11.	8.	9.	8.	10.	12.	12.	10.	11.	12.
13.	13.	12.	12.	11.	12.	12.	12.	12.	15.	17.	17.	13.	11.	11.	11.	12.	10.	11.	12.
10.	11.	12.	12.	10.	11.	11.	12.	12.	12.	12.	11.	11.	12.	12.	11.	12.	11.	11.	12.
12.	11.	11.	13.	12.	11.	11.	12.	12.	12.	14.	14.	13.	13.	12.	12.	13.	12.	13.	13.
20.	23.	10.	12.	12.	11.	11.	11.	13.	13.	13.	12.	11.	12.	9.	10.	11.	11.	13.	12.
13.	12.	11.	11.	10.	10.	10.	9.	10.	10.	10.	10.	10.	13.	11.	9.	12.	12.	11.	10.
13.	14.	12.	13.	11.	9.	7.	8.	9.	8.	8.	9.	10.	9.	10.	10.	10.	11.	12.	12.
11.	10.	10.	10.	11.	12.	10.	9.	9.	12.	11.	13.	11.	10.	11.	10.	10.	12.	11.	11.
13.	13.	12.	13.	13.	12.	11.	9.	8.	11.	12.	11.	10.	10.	9.	11.	13.	15.	17.	15.
12.	13.	13.	14.	14.	17.	14.	12.	9.	9.	11.	11.	15.	16.	18.	17.	12.	13.	20.	30.
13.	16.	15.	24.	22.	23.	14.	12.	12.	11.	12.	13.	15.	16.	18.	15.	12.	12.	17.	30.
13.	13.	14.	21.	19.	22.	13.	13.	12.	11.	11.	12.	17.	17.	19.	16.	14.	16.	17.	32.
20.	13.	12.	11.	11.	12.	11.	11.	11.	12.	11.	11.	10.	10.	10.	10.	10.	11.	12.	14.

REGION NUMBERS FOR REFERENCE SCENE

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	2	2	2
1	1	1	1	1	1	1	3	1	1	1	2	2	2	2	1	1	2	1	1
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	1	1	2	1	1
1	1	1	1	1	1	1	1	1	4	4	4	1	1	1	1	1	2	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	3	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1
1	1	1	1	1	1	1	2	2	2	2	2	2	1	2	2	1	1	1	1
1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
1	1	1	1	1	1	2	2	2	1	1	1	2	2	2	2	2	1	1	1
1	1	1	1	1	1	2	2	2	1	1	1	2	2	2	2	1	4	4	4
1	1	1	1	1	1	1	1	2	2	1	1	4	4	4	4	1	1	4	5
1	1	1	3	3	3	1	1	1	1	1	1	4	4	4	4	1	1	4	5
1	1	1	3	3	3	1	1	1	1	1	1	4	4	4	4	4	4	4	5
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Fig. A-5 — Region 17 intensity level and region map

TERRAIN TYPE(AGRI,MNTN,DSRT,URBB)= 4

REGION 17 USED FOR REFERENCE SCENE

SQRT(NR,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 11.34000, VARIANCE = 4.04442

Ordinary Correlation Algorithm

PROD. ALGORITHM; NORMALIZED? (0=NO,1=YES) = 1

-0.02556	0.03240	0.10614	0.15567	0.20170	0.07400	-0.02273	-0.03850	-0.04477	-0.02603	-0.05280
-0.05168	-0.03331	0.04920	0.15059	0.19335	0.08028	0.02147	0.00105	-0.06712	-0.07789	0.01888
-0.08678	-0.12324	-0.09403	0.05692	0.15338	0.16123	0.10409	0.01690	0.04081	0.10062	0.05359
-0.17744	0.04503	0.20641	0.21425	0.22833	0.16208	0.00928	-0.10812	-0.10080	-0.07433	0.02411
-0.14507	-0.08834	0.09948	0.25248	0.28057	0.25058	0.07916	-0.01089	-0.01277	0.04277	0.17950
-0.02881	0.06938	0.21952	0.42411	0.72206	0.99999	0.61718	0.33277	0.22457	0.11422	0.09249
-0.03376	-0.02136	0.05340	0.10440	0.15331	0.24702	0.29160	0.20289	0.04994	-0.03089	-0.01843
-0.09418	-0.14791	-0.25243	-0.17234	-0.03609	0.10471	0.22303	0.26685	0.27446	0.14083	-0.03723
-0.18824	-0.23126	-0.30262	-0.21439	-0.14707	-0.06789	-0.03273	-0.03152	-0.06124	-0.16063	-0.22098
-0.37366	-0.33396	-0.48102	-0.44455	-0.37994	-0.22874	-0.13855	-0.11055	-0.12043	-0.23585	-0.23872
-0.25195	-0.34374	-0.36447	-0.38563	-0.37104	-0.28926	-0.19541	-0.14790	-0.17737	-0.21469	-0.20635

HALF POINTS (COL,ROW): (7.41, 6.00), (6.00, 6.66), (4.25, 6.00), (6.00, 5.33),

SCENE RESOLUTION IS 4.136

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99999

PMEANJ	PVARJ	QI	M	RHO	VAR(0)	XARG	PCE
-0.01	0.04	34.01	24.18	2.03	0.08		

P-C	XARG	K	A	B
0.979	-2.027	2.050	0.707	4.917

NOTE: XARG=A(K-B)

NO NOISE: P-C ARGUMENT = -2.027
S/N = 0.50: XARG = 0.683, P-C = 0.753

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-6 — Region 17 correlation surface—ordinary correlation

TERRAIN TYPE(AGRI,MNTJ,DSRT,SBRB)= 4

REGION 17 USED FOR REFERENCE SCENE

SCRT(NR,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 11.34000, VARIANCE = 4.34442

Hybrid Algorithm

PROD. ALGORITHM; NORMALIZED? (0=NO,1=YES) = 1

-0.00588	0.08368	0.11016	0.25599	0.33241	0.20709	0.10872	0.02028	-0.03376	0.00668	-0.03824
-0.09531	-0.13395	0.00242	0.20387	0.33246	0.19425	0.22969	0.18492	-0.00084	0.03328	0.06718
-0.08090	-0.15730	-0.08970	0.05126	0.17353	0.18866	0.19578	0.06537	-0.01136	-0.07482	-0.28173
-0.13090	-0.09376	0.03130	0.06200	0.19257	0.18233	0.02128	-0.04015	0.00760	-0.01955	-0.05542
-0.17897	-0.03674	-0.04470	0.07273	0.05372	0.07434	-0.06396	-0.16049	-0.06227	-0.11424	-0.04763
0.01083	0.07657	0.05581	0.17942	0.40137	0.98999	0.45299	0.12859	-0.05999	-0.13731	-0.12103
-0.16498	-0.10734	0.02318	0.09226	0.02748	0.00342	0.09751	0.04352	-0.04724	-0.06826	-0.06917
-0.15188	-0.17665	-0.19165	-0.14492	-0.01818	0.10192	0.17327	0.20592	0.17099	0.07805	0.01614
-0.35326	-0.31333	-0.30656	-0.25097	-0.20571	-0.08894	0.01792	0.12157	0.07628	-0.04513	-0.09101
-0.35490	-0.25327	-0.28509	-0.28789	-0.25448	-0.07319	0.08223	0.28252	0.41252	0.23342	0.10524
-0.18479	-0.16661	-0.13913	-0.12662	-0.25265	-0.18029	-0.07924	0.05833	0.10786	0.10746	0.14056

HALF POINTS (COL,ROW): (6.92, 6.00), (6.00, 6.50), (5.16, 6.00), (6.00, 5.46),

SCENE RESOLUTION IS 2.743

MATCH AT COL 6, ROW 6, PHIM(0)= 0.98999

PMEANJ	PVARJ	Q1	N1	RHO	VAR(0)	XARG	PCE
-0.00	0.03	48.54	36.46	1.66	0.05		

P-C	XARG	K	A	B
0.397	-2.719	2.192	0.707	6.038

NOTE: XARG=A(K-B)

NO NOISE: P-C ARGUMENT = -2.719
S/N = 0.50: XARG = 1.121, P-C = 0.869

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-7 — Region 17 correlation surface—hybrid algorithm

TERRAIN TYPE(AGRI,MNTN,DSRT,SBRB)= 4

REGION 17 USED FOR REFERENCE SCENE

SORT(N,K,N,M),Q= 20 13 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SUBREGION	MEAN	VARIANCE	OF SENSOR SCENE
1	12.03125	1.33027	
2	9.25000	1.00000	
3	19.00000	0.0	
4	16.33333	0.88892	

Feature Matching Correlation Algorithm

PROC. ALGORITHM: NORMALIZED? (0=NO,1=YES) = 1

0.05359	0.03228	0.04483	0.02953	-0.02887	-0.01800	-0.03086	-0.08975	-0.13551	-0.19274	-0.04959
0.07576	0.00932	0.07385	0.20482	0.25458	0.02529	-0.01644	-0.07588	0.00995	0.00260	0.11252
-0.03756	-0.12969	-0.02599	0.08005	0.23034	0.12641	0.04948	0.08332	0.01557	-0.06670	-0.28376
-0.04166	-0.00754	0.01001	0.08333	0.23932	0.27836	0.20626	0.08229	0.11886	0.04480	-0.04147
-0.03457	0.05400	0.09438	0.04279	0.17377	0.19113	0.06180	-0.02467	-0.10202	-0.08440	-0.10024
-0.10592	-0.03733	0.01530	0.24583	0.43621	0.98999	0.39181	0.22740	-0.04863	-0.04471	-0.02989
-0.24269	-0.16469	-0.05353	0.07477	0.06452	0.15167	0.19732	0.07336	0.03269	0.00260	-0.20060
-0.11557	-0.16534	-0.03686	0.01246	0.13304	0.17708	0.18656	0.25835	0.12302	0.13527	-0.04134
-0.14634	-0.17271	-0.16276	-0.21263	-0.17021	-0.11677	-0.00091	0.18604	0.11645	0.04311	0.04682
-0.06637	-0.03494	-0.13732	-0.21515	-0.22418	-0.16513	0.04880	0.26225	0.22622	0.20377	0.16265
-0.00472	-0.14750	-0.06889	-0.14374	-0.23900	-0.19218	-0.24317	-0.00690	0.01486	0.06016	0.11325

HALF POINTS (COL,ROW): (6.83, 6.00), (6.00, 6.59), (5.11, 6.00), (6.00, 5.38),

SCENE RESOLUTION IS 2.045

MATCH AT COL 6, ROW 6, PHIM(O)= 0.98999

MMEANJ	PVARJ	GI	NI	RHO	VAR(O)	XARG	PCE
0.01	0.02	22.89	48.90	1.43	0.04		

P-C	XARG	K	A	B
1.000	-3.324	2.252	0.707	6.993

NOTE: XARG=A(K-B)

NO NOISE: P-C ARGUMENT = -3.324
S/N = 0.50: XARG = 1.512, P-C = 0.935

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-8 — Region 17 correlation surface–feature matching algorithm

TERRAIN TYPE(AGRI,MNTN,CSRT,S2R3)= 3

REGION 10 USED FOR REFERENCE SCENE

24.	25.	26.	25.	25.	26.	26.	27.	27.	26.	26.	26.	26.	26.	26.	26.	25.	25.	26.	25.
24.	24.	24.	24.	24.	24.	25.	25.	25.	25.	24.	24.	24.	24.	24.	25.	25.	24.	24.	24.
25.	25.	25.	24.	25.	25.	25.	25.	25.	25.	25.	25.	24.	24.	24.	24.	24.	25.	24.	24.
24.	25.	25.	24.	24.	25.	24.	25.	25.	25.	25.	24.	25.	25.	25.	24.	24.	24.	25.	24.
24.	25.	25.	25.	25.	25.	25.	25.	25.	24.	24.	25.	25.	24.	24.	24.	24.	24.	24.	24.
25.	25.	25.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	23.	24.	24.	24.	24.	24.
26.	26.	26.	25.	24.	24.	25.	25.	25.	25.	25.	25.	24.	24.	24.	24.	24.	24.	25.	25.
24.	25.	25.	25.	25.	25.	24.	24.	24.	24.	24.	23.	24.	23.	23.	24.	24.	24.	24.	24.
24.	24.	24.	25.	25.	25.	25.	25.	24.	24.	24.	24.	24.	25.	25.	25.	24.	24.	24.	24.
24.	24.	25.	25.	24.	24.	24.	25.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.
25.	25.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.
26.	25.	26.	25.	24.	24.	25.	25.	25.	24.	24.	24.	24.	24.	24.	24.	24.	25.	25.	24.
27.	26.	26.	26.	26.	26.	26.	25.	25.	25.	25.	25.	25.	25.	25.	25.	24.	24.	25.	25.
26.	25.	25.	25.	25.	25.	25.	25.	25.	24.	24.	24.	24.	23.	23.	24.	24.	24.	24.	24.
26.	26.	26.	25.	24.	24.	24.	25.	25.	24.	25.	24.	24.	24.	24.	25.	24.	24.	24.	24.
26.	26.	25.	24.	24.	25.	24.	24.	24.	24.	24.	25.	25.	25.	24.	24.	24.	25.	25.	25.
25.	25.	25.	25.	24.	24.	24.	24.	25.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	25.
25.	25.	24.	24.	25.	24.	24.	24.	25.	24.	24.	24.	25.	25.	24.	24.	24.	24.	25.	25.
27.	26.	26.	25.	25.	24.	25.	25.	25.	25.	25.	25.	25.	25.	25.	24.	24.	25.	25.	25.
25.	25.	25.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.

REGION NUMBERS FOR REFERENCE SCENE

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Fig. A-9 — Region 10 intensity level and region map

TERRAIN TYPE(AGRI,MNTN,DSRT,URBN)= 3

REGION 10 USED FOR REFERENCE SCENE

SQRT(NR,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 24.28999, VARIANCE = 0.36621

Ordinary Correlation Algorithm

PROD. ALGORITHM: NORMALIZED? (0=NO,1=YES) = 1

-0.11107	-0.11362	-0.18076	-0.14033	-0.06979	-0.11119	-0.19839	-0.19192	-0.19702	-0.20318	-0.13184
-0.00716	0.01045	0.15594	0.21947	0.15661	0.18381	0.12222	0.09942	-0.00300	-0.00761	-0.01269
-0.10479	-0.07362	-0.10391	-0.03797	0.04013	-0.01715	0.01823	0.06574	0.01672	0.00246	-0.01269
0.27620	0.24350	0.14929	0.00224	-0.03326	0.05482	0.14911	0.08970	0.08621	-0.03629	0.07417
0.10686	0.10740	0.06409	0.03017	-0.00856	-0.00753	0.02488	0.05898	0.05477	-0.06051	-0.12888
0.42995	0.42352	0.43054	0.56764	0.72421	0.99914	0.65891	0.49128	0.38672	0.28135	0.24712
0.18313	0.11120	0.13856	0.17796	0.04666	-0.02354	-0.05690	-0.03853	-0.09070	-0.27318	-0.18787
0.22710	0.18242	0.13443	0.02311	0.00394	0.07274	0.07269	0.09317	0.03600	0.05713	0.03600
0.18801	0.17123	0.01323	-0.10051	-0.05936	0.06406	0.05390	0.07357	0.11805	0.14225	0.10640
0.04436	0.05195	0.07889	0.06819	0.02382	0.02880	0.07839	0.06588	0.06322	-0.01850	0.05294
0.08681	-0.01349	-0.11289	-0.08805	-0.05500	-0.05106	0.02617	0.07590	0.02959	-0.12127	-0.11353

HALF POINTS (COL,ROW): (7.95, 6.00), (6.00, 6.49), (3.50, 6.00), (6.00, 5.50),

SCENE RESOLUTION IS 2.708

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99914

PMEANJ	PVARJ	QE	WE	RHO	VAR(0)	XARG	PCE
0.06	0.03	49.08	36.93	1.65	0.05		

P-C	XARG	K	A	B
0.997	-2.744	2.197	0.707	6.077

NOTE: XARG=A(K-B)

NO NOISE: P-C ARGUMENT = -2.744
S/N = 0.50: XARG = 1.136, P-C = 0.872

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-10 — Region 10 correlation surface—ordinary correlation

TERRAIN TYPE(AGRI,MNTN,DSRT,URBB)= 3

REGION 10 USED FOR REFERENCE SCENE

SQRT(NB,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 24.28999, VARIANCE = 0.36621

Hybrid Algorithm

PROC. ALGORITHM; NORMALIZED? (0=NO,1=YES) = 1

-0.11107	-0.11362	-0.18076	-0.14033	-0.06979	-0.11119	-0.19839	-0.19192	-0.19702	-0.20318	-0.13184
-0.00716	0.01045	0.15594	0.21947	0.15661	0.18381	0.12222	0.09942	-0.00300	-0.00761	-0.01269
-0.10479	-0.07562	-0.10391	-0.03797	0.04013	-0.01715	0.01823	0.06574	0.01672	0.00246	-0.01269
0.27620	0.24350	0.14929	0.00224	-0.03326	0.05482	0.14911	0.08970	0.08621	-0.03629	0.07417
0.10686	0.10740	0.06409	0.03017	-0.00856	-0.00753	0.02488	0.05898	0.05477	-0.06051	-0.12888
0.42995	0.42352	0.43054	0.56764	0.72421	0.99914	0.65891	0.49128	0.38672	0.28135	0.24717
0.18313	0.11120	0.13856	0.17796	0.04666	-0.02354	-0.05690	-0.03853	-0.09070	-0.21318	-0.18787
0.22710	0.13242	0.13443	0.02311	0.00394	0.07274	0.07269	0.09317	0.03600	0.05713	0.03600
0.18801	0.17123	0.01323	-0.10051	-0.05936	0.06406	0.05390	0.07357	0.11805	0.14225	0.10640
0.04436	0.05195	0.07889	0.06819	0.02382	0.02880	0.07839	0.06588	0.06322	-0.01850	0.05294
0.08681	-0.01349	-0.11289	-0.08805	-0.05500	-0.05106	0.02617	0.07590	0.02959	-0.12127	-0.11353

HALF POINTS (COL,ROW): (7.95, 6.00), (6.00, 6.49), (3.50, 6.00), (6.00, 5.50),

SCENE RESOLUTION IS 2.708

MATCH AT COL 6, ROW 6, PHIN(0)= 0.99914

PMEANJ	PVARJ	QI	NA	RHO	VAR(0)	XARG	PCE
0.06	0.03	49.08	36.93	1.65	0.05		

P-C	XARG	K	A	B	NOTE: XARG=A(K-B)
0.997	-2.744	2.197	0.707	6.077	

NO NOISE: P-C ARGUMENT = -2.744
S/N = 0.50: XARG = 1.136, P-C = 0.872

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-11 — Region 10 correlation surface—hybrid algorithm

TERRAIN TYPE(AGRI.MNTN.DSRT.SBRB)= 3

REGION 10 USED FOR REFERENCE SCENE

S.HT.SR.N.M).C= 20 1. 1. 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SUBREGION MEAN VARIANCE OF SENSOR SCENE
1 24.28555 0.36621

Feature Matching Correlation Algorithm

PROG. ALGORITHM: NORMALIZED? (0=NO,1=YES) = 1

-0.11107	-0.11862	-0.13076	-0.14033	-0.06979	-0.11119	-0.19839	-0.19192	-0.19702	-0.20318	-0.13184
-0.05716	0.01045	0.15594	0.21947	0.15661	0.18381	0.12222	0.09942	-0.00300	-0.00761	-0.01269
-0.10475	-0.07562	-0.10391	-0.03797	0.04013	-0.01715	0.01823	0.06574	0.01672	0.00246	-0.01269
0.27620	0.24350	0.14329	0.00224	-0.03326	0.05482	0.14911	0.08970	0.08621	-0.03629	0.07417
0.10666	0.10743	0.06405	0.03317	-0.00856	-0.00753	0.02488	0.05898	0.05477	-0.06051	-0.12888
0.42995	0.42352	0.42354	0.56764	0.72421	0.99914	0.65891	0.49128	0.38672	0.28135	0.24717
0.18313	0.11120	0.13056	0.17796	0.04666	-0.02354	-0.05690	-0.03853	-0.09070	-0.21318	-0.18787
0.22710	0.18242	0.13443	0.02311	0.00394	0.07274	0.07269	0.09317	0.03600	0.05713	0.03600
0.18801	0.17123	0.01323	-0.10051	-0.05936	0.06406	0.05390	0.07357	0.11805	0.14225	0.10640
0.04436	0.05195	0.07689	0.06819	0.02382	0.02880	0.07839	0.06588	0.06322	-0.01850	0.05294
0.06661	-0.01349	-0.11289	-0.08805	-0.05500	-0.05106	0.02617	0.07590	0.02959	-0.12127	-0.11353

HALF POINTS (COL,ROW): (7.95, 6.00), (6.00, 6.49), (3.50, 6.00), (6.00, 5.50),

SCENE RESOLUTION IS 2.708

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99914

MMEANJ	MVARJ	CI	NI	RHO	VAR(J)	XARG	PCE
0.06	0.03	49.68	36.93	1.65	0.05		

P-C	XARG	K	A	B
0.997	-2.744	2.197	0.707	6.077

NOTE: XARG=A(K-B)

NO NOISE: P-C ARGUMENT = -2.744
S/N = 3.50: XARG = 1.136, P-C = 0.872

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-12 — Region 10 correlation surface—feature matching algorithm

TERRAIN TYPE(AGRI,MNTN,DSRT,SBRB)= 3

REGION 6 USED FOR REFERENCE SCENE

29.	30.	31.	31.	31.	30.	29.	29.	29.	27.	26.	26.	26.	26.	26.	25.	24.	24.	25.	27.
27.	28.	30.	30.	30.	29.	29.	29.	29.	30.	29.	28.	28.	28.	26.	25.	25.	25.	26.	27.
30.	31.	32.	31.	32.	33.	31.	31.	30.	30.	31.	30.	30.	28.	27.	26.	25.	24.	26.	27.
29.	29.	29.	30.	30.	30.	29.	29.	29.	29.	29.	30.	29.	27.	25.	25.	24.	24.	24.	25.
29.	29.	30.	31.	31.	31.	30.	29.	29.	29.	29.	30.	31.	28.	28.	26.	25.	25.	24.	25.
29.	30.	30.	28.	33.	33.	33.	30.	29.	28.	28.	28.	28.	29.	27.	25.	25.	24.	23.	25.
29.	29.	31.	31.	33.	32.	32.	31.	31.	30.	29.	28.	28.	29.	24.	24.	23.	23.	25.	27.
30.	31.	31.	30.	30.	30.	30.	33.	32.	31.	28.	29.	30.	26.	24.	24.	24.	24.	25.	26.
30.	31.	30.	30.	32.	33.	32.	32.	31.	30.	30.	32.	29.	27.	25.	25.	25.	27.	28.	28.
30.	30.	30.	28.	29.	31.	30.	30.	30.	28.	28.	28.	27.	26.	24.	24.	25.	26.	26.	26.
29.	28.	28.	29.	29.	31.	30.	29.	28.	28.	27.	26.	26.	25.	24.	24.	24.	26.	26.	26.
29.	28.	28.	29.	29.	30.	29.	29.	28.	27.	27.	26.	25.	24.	24.	24.	25.	27.	27.	26.
29.	30.	30.	30.	30.	30.	29.	29.	28.	26.	26.	25.	25.	25.	25.	26.	27.	27.	26.	26.
28.	29.	30.	30.	29.	29.	29.	28.	27.	25.	25.	24.	25.	27.	25.	25.	25.	26.	25.	25.
30.	30.	31.	31.	31.	30.	29.	29.	27.	26.	26.	26.	26.	26.	26.	27.	26.	26.	26.	26.
28.	29.	29.	29.	28.	28.	29.	28.	27.	26.	26.	26.	25.	25.	25.	25.	25.	25.	25.	25.
30.	29.	29.	30.	30.	29.	29.	29.	28.	26.	24.	25.	26.	25.	26.	25.	24.	24.	26.	26.
29.	29.	30.	30.	30.	29.	29.	29.	28.	25.	25.	25.	25.	25.	25.	25.	24.	25.	25.	25.
29.	29.	30.	30.	30.	30.	30.	29.	26.	24.	24.	24.	25.	26.	25.	26.	25.	25.	25.	25.
29.	29.	30.	30.	29.	29.	29.	28.	27.	26.	26.	24.	25.	25.	24.	24.	24.	25.	25.	24.

REGION NUMBERS FOR REFERENCE SCENE

1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2

Fig. A-13 — Region 6 intensity level and region map

TERRAIN TYPE(AGRI,MNTN,DSRT,URBN)= 3

REGION 6 USED FOR REFERENCE SCENE

SQRT(NR,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 28.09000, VARIANCE = 5.92212

Ordinary Correlation Algorithm

PROD. ALGORITHM: NORMALIZED? (0=NO,1=YES) = 1

-0.20608	-0.00378	0.13403	0.21795	0.33517	0.44838	0.53229	0.58314	0.62839	0.62008	0.51261
-0.16380	0.06344	0.23707	0.32221	0.47836	0.58603	0.64979	0.69086	0.74482	0.72473	0.60152
0.05826	0.22824	0.33348	0.40501	0.57414	0.66153	0.68971	0.73694	0.72948	0.67363	0.56698
0.14683	0.34412	0.50494	0.57027	0.66706	0.69757	0.74489	0.74741	0.67600	0.61916	0.47795
0.26539	0.49011	0.59553	0.66538	0.75177	0.83497	0.84278	0.76107	0.65499	0.53626	0.36427
0.34174	0.51802	0.61209	0.72040	0.87211	0.99996	0.88560	0.76982	0.63736	0.48823	0.33443
0.34321	0.52705	0.61794	0.71102	0.82661	0.85580	0.78674	0.71587	0.57261	0.40766	0.27124
0.41342	0.54013	0.60230	0.71384	0.76115	0.76570	0.72592	0.64744	0.49500	0.34642	0.24266
0.38679	0.51739	0.60137	0.69548	0.73724	0.74358	0.67261	0.56982	0.41299	0.27903	0.25656
0.42655	0.54339	0.62930	0.68884	0.73230	0.73770	0.65430	0.56664	0.36638	0.21167	0.17995
0.41417	0.53477	0.62766	0.67472	0.69893	0.69503	0.62305	0.54182	0.37506	0.21772	0.15227

HALF POINTS (COL,ROW): (9.92, 6.00), (6.00,12.00), (1.90, 6.00), (6.00, 1.37),

SCENE RESOLUTION IS 4.768

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99996

PMEANJ	PVARJ	MI	NA	RHO	VAR(0)	XARG	PCE
0.53	0.05	30.13	20.98	2.18	0.10		

P-C	XARG	K	A	B	NOTE: XARG=A(K-B)
0.966	-1.824	2.000	0.707	4.580	

NO NOISE: P-C ARGUMENT = -1.824
S/N = 0.50: XARG = 0.558, P-C = 0.711

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-14 — Region 6 correlation surface—ordinary correlation

TERRAIN TYPE(AGRI,MNTN,DSRT,URBN)= 3

REGION 6 USED FOR REFERENCE SCENE

SQRT(NR,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 28.09000, VARIANCE = 5.92212

Hybrid Algorithm

PROD. ALGORITHM; NORMALIZED? (0=NO,1=YES) = 1

-0.25814	-0.03334	0.05722	0.12951	0.16406	0.25502	0.28390	0.31811	0.38395	0.42678	0.29597
-0.21668	0.01103	0.17131	0.22211	0.27977	0.30203	0.29751	0.29680	0.40144	0.44094	0.30726
-0.02901	0.09302	0.10742	0.10628	0.23606	0.31398	0.24891	0.29267	0.33965	0.25173	0.04388
0.00469	0.09704	0.19977	0.23870	0.30223	0.29477	0.30427	0.34096	0.23771	0.10744	-0.10528
0.05420	0.18361	0.25851	0.33970	0.41815	0.55082	0.55904	0.42947	0.26328	0.03221	-0.19064
0.07418	0.18335	0.26769	0.45263	0.68399	0.99983	0.71797	0.50377	0.29199	0.07754	-0.09661
0.05126	0.22332	0.31472	0.46802	0.59308	0.65565	0.56891	0.48631	0.31165	0.10174	-0.07058
0.14855	0.22869	0.28543	0.47547	0.46173	0.53101	0.52761	0.48746	0.33025	0.08568	-0.04018
0.04718	0.20232	0.30561	0.43438	0.49204	0.55086	0.49930	0.39887	0.30725	0.14227	0.11048
0.08146	0.25950	0.37243	0.42085	0.49635	0.53498	0.48358	0.43610	0.33085	0.21167	0.17995
0.11066	0.22669	0.34092	0.35383	0.37290	0.41385	0.38591	0.39271	0.35315	0.21772	0.15227

HALF POINTS (COL,ROW): (8.02, 6.00), (6.00,10.29), (4.20, 6.00), (6.00, 4.80).

SCENE RESOLUTION IS 3.662

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99983

PMEANJ	PVARJ	QI	NI	RHO	VAR(0)	XARG	PCE
0.27	0.04	37.76	27.31	1.91	0.07		

P-C	XARG	K	A	B	NOTE: XARG=A(K-B)
0.987	-2.216	2.093	0.707	5.226	

NO NOISE: P-C ARGUMENT = -2.216
S/N = 0.50: XARG = 0.801, P-C = 0.788

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-15 — Region 6 correlation surface—hybrid algorithm

TERRAIN TYPE(AGRI,MNTN,DSRT,SBPB)= 3

REGION 6 USED FOR REFERENCE SCENE

SQRT(NR,N,M),C= 20 13 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SUBREGION	MEAN	VARIANCE OF SENSOR SCENE
1	29.58112	2.13232
2	25.95744	1.61523

Feature Matching Correlation Algorithm

PROC. ALGORITHM: NORMALIZED? (0=NO,1=YES) = 1

-0.07441	0.13141	0.17762	0.12118	-0.00978	-0.06493	-0.15049	-0.12254	0.03796	0.12668	0.16129
0.01155	0.25160	0.30141	0.15849	0.06267	-0.07744	-0.15446	-0.19759	-0.01981	0.13558	0.07497
0.05963	0.23399	0.27285	0.15317	0.22475	0.14928	-0.01278	-0.07973	0.02927	-0.03988	-0.18747
0.06084	0.24773	0.43448	0.33776	0.28317	0.25402	0.18508	0.17956	0.05779	-0.07875	-0.13718
0.04075	0.20173	0.26381	0.28980	0.31246	0.53300	0.45105	0.31014	0.04182	-0.06018	-0.13955
[illegible]	-0.01942	0.03680	0.27306	0.56770	0.99983	0.56990	0.31685	0.05905	0.00631	-0.03290
-0.20860	-0.11132	-0.01176	0.24016	0.38916	0.57312	0.30445	0.22408	0.08501	0.07797	0.06059
-0.06619	-0.12847	-0.06331	0.15200	0.14820	0.27783	0.19420	0.18344	0.12965	0.08857	0.06041
-0.16607	-0.17694	-0.12968	-0.07029	0.06446	0.17964	0.19264	0.13152	0.21782	0.23616	0.22709
-0.02591	-0.05329	-0.07922	-0.10213	0.02386	0.11749	0.19864	0.26689	0.35699	0.35733	0.25298
0.00837	-0.15772	-0.12548	-0.09881	0.00816	0.17421	0.17264	0.26932	0.34210	0.29278	0.12289

HALF POINTS (COL,ROW): (7.28, 6.00), (6.00, 7.25), (4.77, 6.00), (6.00, 4.68),

SCENE RESOLUTION IS 3.203

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99983

PMEANJ	PVARJ	QI	NI	RHO	VAR(J)	XARG	PCE
0.11	0.03	42.40	31.22	1.79	0.06		

P-C	XARG	K	A	B
0.993	-2.439	2.139	0.707	5.588

NOTE: XARG=A(K-B)

NO NOISE: P-C ARGUMENT = -2.439
S/N = 0.50: XARG = 0.941, P-C = 0.827

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-16 — Region 6 correlation surface—feature matching algorithm

TERRAIN TYPE(AGRI,HUT?,USRT,SBRB)= 1

REGION 12 USED FOR REFERENCE SCENE

20.	21.	22.	21.	22.	22.	22.	22.	22.	21.	17.	15.	15.	15.	16.	15.	15.	20.	24.	25.
20.	20.	21.	21.	21.	21.	21.	21.	21.	21.	18.	14.	13.	13.	13.	14.	14.	17.	22.	23.
22.	20.	21.	22.	22.	22.	21.	21.	22.	21.	20.	17.	15.	15.	15.	14.	14.	16.	21.	23.
21.	21.	21.	21.	21.	22.	21.	21.	22.	21.	22.	18.	14.	15.	14.	14.	14.	15.	21.	23.
20.	20.	22.	22.	21.	21.	21.	22.	22.	22.	21.	18.	14.	14.	14.	13.	13.	14.	21.	24.
21.	21.	21.	21.	21.	21.	21.	22.	21.	21.	21.	18.	14.	14.	14.	13.	13.	15.	20.	24.
21.	21.	22.	22.	22.	22.	22.	23.	23.	22.	21.	18.	15.	15.	14.	14.	14.	16.	18.	19.
20.	20.	21.	21.	21.	21.	21.	21.	21.	20.	20.	18.	14.	14.	15.	14.	14.	14.	15.	16.
20.	20.	21.	22.	22.	21.	21.	21.	21.	20.	21.	21.	19.	14.	14.	14.	14.	14.	15.	16.
21.	20.	19.	21.	21.	21.	22.	22.	22.	22.	22.	22.	20.	14.	13.	14.	14.	14.	15.	15.
15.	15.	17.	22.	22.	23.	23.	22.	21.	21.	23.	24.	22.	14.	12.	13.	14.	14.	14.	15.
14.	14.	15.	21.	22.	23.	23.	22.	22.	22.	23.	24.	22.	15.	12.	13.	13.	14.	14.	14.
15.	15.	17.	22.	24.	24.	23.	22.	22.	23.	24.	25.	23.	16.	13.	13.	15.	14.	15.	16.
14.	14.	15.	20.	22.	22.	22.	21.	21.	22.	23.	23.	22.	16.	13.	13.	14.	14.	14.	15.
15.	14.	14.	15.	21.	23.	21.	22.	21.	21.	22.	23.	23.	22.	15.	13.	13.	15.	15.	15.
15.	14.	14.	15.	21.	23.	22.	23.	22.	22.	23.	24.	23.	23.	16.	13.	13.	14.	15.	15.
14.	14.	14.	14.	20.	23.	23.	23.	22.	22.	22.	22.	21.	21.	17.	14.	13.	14.	14.	14.
14.	14.	14.	14.	19.	23.	23.	23.	22.	22.	22.	23.	21.	19.	16.	15.	16.	19.	21.	22.
15.	15.	16.	18.	20.	23.	24.	23.	21.	19.	21.	22.	23.	24.	23.	23.	23.	24.	23.	25.
17.	17.	17.	17.	19.	19.	18.	17.	18.	19.	22.	24.	25.	23.	23.	23.	23.	23.	24.	24.

REGION NUMBERS FOR REFERENCE SCENE

2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4	4	4
2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4	4
2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4	4
2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	4	4
2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	4	4
2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	4	4
2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	4	4
2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3
1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3
1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3
1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	2	2	2
1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Fig. A-17 — Region 12 intensity level and region map

TERRAIN TYPE(AGRI,MNTN,DSRT,URBB)= 1

REGION 12 USED FOR REFERENCE SCENE

S(RT(NB,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 20.06000, VARIANCE = 11.61646

Ordinary Correlation Algorithm

PROD. ALGORITHM; NORMALIZED? (0=NO,1=YES) = 1

-0.13505	0.20507	0.57940	0.81752	0.88418	0.75326	0.60626	0.49890	0.32162	-0.09394	-0.51811
-0.10952	0.02638	0.42696	0.73386	0.87809	0.80467	0.65382	0.52705	0.37935	0.04335	-0.33147
-0.13010	-0.08330	0.20246	0.62573	0.85614	0.84850	0.69907	0.54917	0.41103	0.14505	-0.17940
-0.17614	-0.15386	0.06012	0.51982	0.84176	0.90073	0.75170	0.56693	0.42671	0.20655	-0.05852
-0.23708	-0.23266	-0.08011	0.41797	0.82765	0.93378	0.78995	0.58912	0.43881	0.25893	0.02353
-0.23645	-0.24421	-0.13674	0.30818	0.81065	0.99999	0.85652	0.62887	0.44984	0.30527	0.13239
-0.26315	-0.26389	-0.21426	0.14839	0.68715	0.93057	0.86146	0.65075	0.46763	0.33469	0.21228
-0.26801	-0.27041	-0.28176	-0.03766	0.56424	0.86690	0.88052	0.70944	0.52219	0.39366	0.27763
-0.30141	-0.30029	-0.33468	-0.20025	0.44411	0.79931	0.88623	0.76290	0.56515	0.41916	0.30927
-0.32970	-0.32788	-0.37697	-0.30375	0.30333	0.72246	0.87101	0.78929	0.58515	0.41960	0.29956
-0.36460	-0.34483	-0.40086	-0.36384	0.11089	0.56617	0.77376	0.73931	0.56568	0.40954	0.30683

HALF POINTS (COL,ROW): (8.72, 6.00), (6.00,12.00), (4.38, 6.00), (6.00, 0.0),

SCENE RESOLUTION IS 17.840

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99999

PMEANJ	PVARJ	QL	[illegible]	RHO	VAR(0)	XARG	PCE
0.31	0.18	10.35	5.41	4.22	0.36		

P-C	XARG	K	A	B
0.727	-0.603	1.516	0.707	2.369

NOTE: XARG=A(K-B)

NO NOISE: P-C ARGUMENT = -0.0[illegible]3
S/N = 0.50: XARG = -0.128, P-C = 0.449

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-18 — Region 12 correlation surface—ordinary correlation

TERRAIN TYPE(AGRI,MNTN,DSRT,URBN)= 1

REGION 12 USED FOR REFERENCE SCENE

SQRT(NR,N,M),Q= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SENSOR SCENE: MEAN = 20.06000, VARIANCE = 11.61646

Hybrid Algorithm

PROD. ALGORITHM: NORMALIZED? (0=NO,1=YES) = 1

-0.13505	0.13674	0.51820	0.59438	0.23412	-0.15586	-0.06329	0.07992	-0.38554	-0.18426	-0.39966
-0.05016	0.09341	0.40913	0.53959	0.36431	0.04806	0.03043	0.11765	-0.11875	-0.17161	-0.30001
-0.05191	0.00416	0.23679	0.40735	0.38960	0.26428	0.14236	0.10523	-0.11790	-0.15347	-0.22524
-0.00057	-0.01408	0.19924	0.33653	0.48992	0.51387	0.26920	0.09592	-0.07967	-0.18321	-0.20594
-0.07262	-0.09722	0.02464	0.28093	0.49345	0.65822	0.39932	0.16697	-0.05276	-0.15822	-0.26081
0.08458	0.01922	0.03962	0.20273	0.49819	0.99971	0.63294	0.27090	-0.00181	-0.07664	-0.16335
0.04846	-0.04755	-0.09571	0.09111	0.28107	0.62994	0.49147	0.18381	-0.03098	-0.14721	-0.17832
0.07974	-0.06360	-0.19336	-0.01976	0.10928	0.39259	0.42769	0.20963	0.01625	-0.13525	-0.20374
0.02921	-0.12948	-0.31831	-0.07065	0.05361	0.21916	0.34522	0.22436	0.25318	0.02667	-0.16241
0.02993	-0.13354	-0.36967	-0.24704	-0.06594	0.05730	0.13688	0.10455	0.14702	0.06048	-0.13830
-0.10669	-0.18429	-0.36379	-0.33688	-0.14958	-0.11585	0.00016	0.06649	0.10621	0.00560	-0.15901

HALF POINTS (COL,ROW): (7.37, 6.00), (6.00, 7.55), (5.00, 6.00), (6.00, 3.94),

SCENE RESOLUTION IS 5.762

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99971

PMEANJ	PVARJ	Q1	M1	RHO	VAR(0)	XARG	PCE
0.06	0.06	25.59	17.55	2.40	0.12		

P-C	XARG	K	A	B	NOTE: XARG=A(K-B)
0.943	-1.579	1.933	0.707	4.166	

NO NOISE: P-C ARGUMENT = -1.579
S/N = 0.50: XARG = 0.409, P-C = 0.659

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-19 — Region 12 correlation surface–hybrid algorithm

TERRAIN TYPE(AGRI,MNTN,DSRT,SBRB)= 1

REGION 12 USED FOR REFERENCE SCENE

SCRT(I,K,N,M),L= 20 10 11 120. S/N=****** NO.= 77

MATCH POINT SHOULD BE AT COL 6, ROW 6

SUBREGION	MEAN	VARIANCE OF SENSOR SCENE
2	21.74358	1.70410
3	14.09091	1.08264

Feature Matching Correlation Algorithm

PROC. ALGORITHM; NORMALIZED? (0=NO,1=YES) = 1

-0.05657	-0.06750	0.11124	-0.11991	-0.01959	-0.27307	-0.14116	-0.07119	-0.12953	-0.06007	-0.17146
0.03036	0.05514	0.11718	0.06151	0.14423	-0.09231	-0.01368	0.02751	-0.02243	0.06502	0.06250
0.05072	-0.00751	0.02878	0.07489	0.09986	0.06777	-0.04828	-0.12412	-0.16481	-0.06248	-0.07419
0.15574	-0.01718	0.02909	0.15025	0.21576	0.42417	0.01158	-0.06716	-0.20995	-0.15810	-0.05060
0.21192	-0.02947	-0.04898	0.15769	0.23916	0.64844	0.14772	-0.02934	-0.15484	-0.16446	-0.02513
0.29994	0.12384	0.04869	0.25060	0.38400	0.99971	0.34456	0.14764	-0.02884	-0.03207	0.08917
0.11487	-0.01855	-0.11826	0.05719	0.18083	0.62785	0.29906	0.14004	-0.03738	-0.09952	0.00790
0.09659	-0.03005	-0.11718	0.04535	0.01502	0.33189	0.29822	0.15357	0.05656	-0.05405	-0.01936
0.01547	-0.05124	-0.11632	0.01939	-0.12057	0.05149	0.24977	0.13368	0.15316	0.07796	0.00088
-0.02813	-0.02854	-0.13484	-0.06394	-0.17785	-0.20421	0.08947	-0.02580	0.21965	-0.00806	0.01285
-0.15913	-0.08732	-0.06995	-0.02625	-0.09962	-0.15933	0.01394	-0.09070	0.18591	0.07876	-0.03822

HALF POINTS (COL,ROW): (6.76, 6.00), (6.00, 7.43), (5.19, 6.00), (6.00, 4.34),

SCENE RESOLUTION IS 2.441

MATCH AT COL 6, ROW 6, PHIM(0)= 0.99971

PMEANJ	PVARJ	CI	NI	RFC	VAR(0)	XARG	PCE
0.03	0.02	53.77	40.97	1.56	0.05		

P-C	XARG	K	A	B	NOTE: XARG=A(K-B)
0.998	-2.948	2.232	0.707	6.401	

NO NOISE: P-C ARGUMENT = -2.948
S/N = 0.50: XARG = 1.261, P-C = 0.893

MATCH POINT: VARIANCE OF REFERENCE SCENE = 1.00000, VARIANCE OF NOISE = 0.0 , ESTIMATED S/N = **********

Fig. A-20 — Region 12 correlation surface—feature matching algorithm

DAT
FILM
4 -